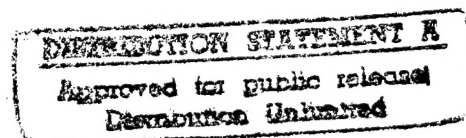




US Army Corps  
of Engineers  
Walla Walla District

# Evaluation of Facilities for Collection, Bypass, and Transportation of Outmigrating Chinook Salmon

Annual Report - 1992



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**EVALUATION OF FACILITIES FOR COLLECTION, BYPASS, AND  
TRANSPORTATION OF OUTMIGRATING CHINOOK SALMON**

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**Annual Report**

**November, 1992**

**(Revised October 1993)**

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## EXECUTIVE SUMMARY

\*Chinook salmon smolts held at low densities (0.06 - 0.08 lbs/gal) in raceways with large (>200 mm) steelhead smolts at the Little Goose facility had plasma cortisol levels similar to chinook held without large steelhead. The presence of steelhead did not appear to be stressful to juvenile chinook.

\*Juvenile chinook passing through the downstream section of the fish size and debris separator at the Little Goose facility were more stressed than fish exiting the upstream section. Smolts exiting the downstream section had higher plasma cortisol and lower plasma chloride concentrations. No differences between the two groups were found in body size, condition factor, gill histology, gill  $\text{Na}^+/\text{K}^+$  ATPase, or incidence and severity of bacterial kidney disease.

\*Chinook held in covered raceways after bypass and separator passage were less stressed than fish held in open raceways, as indicated by plasma cortisol concentrations. The reduction of ambient light levels may be an effective method for reducing the stress response to handling procedures.

\*Stress level (plasma cortisol) was lower in chinook that were loaded directly into barge compartments compared to smolts loaded into raceways at Lower Granite Dam.

\*Turbine bypass and collection of fish at Lower Granite dam was stressful to juvenile spring/summer chinook salmon as judged from significantly increased plasma cortisol levels. Over the course of barging the fish appeared to be recovering from the collection/loading stress; plasma cortisol in general declined, returning to pre-collection levels by the time of release in two of three trials.



\*The immune system of the fish also increased in competence (numbers of antibody-producing cells) by the end of barging, compared to juvenile chinook sampled before loading, suggesting that the fish were in the process of recovering from the loading stress. This difference was significant on two dates.

\*A large majority of all chinook salmon had detectable levels of BKD infection, with 10-30% of fish having levels in the moderate to high range. The percentage of fish with moderate to high levels of infection increased over the course of the run.

\*The degree of smoltification may have increased over the run; gill  $\text{Na}^+/\text{K}^+$  ATPase of migrating chinook increased significantly with each succeeding sampling date.

\*Video tapes filmed inside barge compartments showed conditions similar to what one might expect to see in a hatchery raceway, with few if any aggressive interactions between fish. Release from the barge appears to strongly disturb the fish, and may represent a significant source of stress.

\*Upon release, radiotagged fish rapidly left the release area, moving out of radio range (0.5 mile) within 15 minutes. In general, the majority of tagged fish moved downstream at a rate of 1-2 miles per hour, but there was considerable variation between individuals.

\*Post-release movement patterns of radiotagged fish may have taken them through areas containing large concentrations of predatory squawfish.

## OBJECTIVES

The overall goal of this study is to provide information that can be used to improve facilities and procedures for the collection and transportation of outmigrating chinook salmon from the Snake and Columbia Rivers. The specific objectives we have addressed this year are as follows:

### Objective 1

**Review existing literature concerning the effects of collection, handling and transportation on the stress response and performance of salmonid fishes (with special reference to chinook salmon) and use of this information to develop criteria for the evaluation of existing and proposed facilities and procedures.**

### Objective 2

**Investigate the possible stress response of spring chinook salmon to bypass and collection elements at Little Goose and Lower Granite dams.**

A. Evaluate the stress response to raceway conditions and the Little Goose size separator.

- 1) Determine if plasma cortisol concentrations in chinook salmon are altered by interactions with steelhead or by raceway loading densities.
- 2) Determine if there is a difference in physiological or physical condition of fish exiting from the upstream and downstream sections of the Little Goose fish separator.

B. Evaluate the effect of providing cover on the stress response of chinook salmon.

- 1) Determine if the decline in plasma cortisol concentrations following bypass passage is more rapid if the animals are held in covered rather than uncovered raceways.

### **Objective 3**

**Investigate the possible stress associated with spring chinook transport systems and performance of the fish post-release.**

A. Evaluate the response to barge loading procedures and barge transportation.

- 1) Compare plasma cortisol concentrations in chinook salmon loaded directly into the barges to those held in raceways prior to loading.
- 2) Measure physiological and performance indices of stress during barge transportation.

B. Monitor behavior of chinook salmon during barge transport and after release.

- 1) Document the behavior of fish during barge transport.
- 2) Monitor post-release behavior.

## INTRODUCTION

### **Problem description**

Collection of migrating smolts of steelhead trout and chinook salmon at hydroelectric dams on the Snake and Columbia Rivers and transportation of these fish by barge or truck to the lower Columbia River began in the late 1970's and has continued to the present. Although smolt-to-adult survival rates of steelhead trout have benefitted from the transportation program, survival rates of chinook salmon have continued to decline. The physiological responses of chinook smolts to stressful stimuli experienced during collection and transportation are of concern, because they involve changes in endocrine, metabolic, osmoregulatory, and immune system function, as well as predator avoidance abilities. Measurements of physiological stress indices have been used to identify stressful aspects of collection and transportation at Lower Granite, Little Goose, and McNary dams (Schreck, et al. 1985, Mathews et al. 1986, Maule et al 1988, Congleton and Wagner 1988). Information provided by these studies has been used to improve the collection and transport facilities and has been instrumental in justifying new facility construction.

### **Research on species interactions and loading densities in raceways**

The results of seawater challenge tests carried out at Lower Granite Dam in 1982 indicated that the osmoregulatory performance of spring chinook salmon smolts was impaired after confinement with steelhead smolts for 24 h (Mathews et al. 1986). In contrast, assays of cortisol concentrations in the blood of migrating spring chinook smolts confined with an equal number of steelhead smolts at a density of 0.5 pounds per gallon did not indicate that the chinook salmon were stressed (Congleton et al. 1984). Additional work is needed to determine whether or not spring chinook smolts benefit from segregation from steelhead smolts.

### **Research on effects of barge transportation**

The response of spring chinook salmon to barge transportation has received relatively little attention. Plasma cortisol concentrations declined in eight groups of spring chinook salmon after loading into barges at Lower Granite Dam, but then increased in seven of the eight groups prior to arrival at Bonneville Dam (Congleton et al. 1984). The reason for this apparent stress response is unknown. Loading densities for these groups were low, not exceeding 0.12 pounds/gallon. Plasma cortisol concentrations also declined in four groups of fall chinook salmon after loading into barges at McNary Dam and remained low until fish were removed at Bonneville Dam 15 hours later (Maule et al. 1988). Interestingly, the rise in plasma cortisol observed in fish transported from Lower Granite Dam was not evident for the first 12-16 hours of transportation. Two alternative hypotheses are that the fish were reacting : a) to the noise created by the diesel generators used to run the pumps on the barges, or b) to the new suite of water-borne odors encountered below the confluence of the Snake and Columbia Rivers.

### **Measures to reduce the stress response of chinook salmon**

Previously referenced research at fish collection facilities has identified conditions that elicit a stress response in chinook salmon, including vertical water flow, exposure to extremely shallow water, and bright light. Elimination of procedures that expose fish to bright light during handling may be an effective and inexpensive means of reducing stress. At present, truck and barge loading is performed in unshaded areas during daylight hours.

### **Evaluation of performance capabilities of chinook salmon smolts**

Transportation stress has been shown to reduce smolt-to-adult survival of coho salmon (Schreck et al. 1989). Although survivorship of transported fish is the final measure of performance, survival rates cannot be used to compare the effects of alternative collection and transportation practices because of the number of fish

that must be marked and the time required for all survivors to return. A number of rapid physiological assays and performance indicators has been used to evaluate the responses of fish to stress (reviewed by Schreck, 1991). Performance indicators such as disease resistance, swimming endurance or predator avoidance are of particular interest because impaired performance can reasonably be expected to predict reduced ability to survive in the wild. Disease and predation are believed to be the major causes of mortality for migrating salmon smolts.

Recent work has shown that stress alters disease resistance in salmonids through effects on both immune system function and non-specific resistance factors (Maule et al. 1989). The plasma cortisol response to stressors increases during smoltification (Barton et al. 1985) and elevated cortisol suppresses the antibody-producing cell response to antigenic stimulation (Maule et al. 1987). Because in-river migration stimulates and advances the process of smoltification (Zaugg et al. 1985), immune function in migrating smolts may be more sensitive to stress than immune function in parr or non-migrating (confined) smolts. Stress can reduce the ability of smolts to resist novel pathogens encountered in the marine environment as well as *Renebacterium salmoninarum*, the causative agent of bacterial kidney disease. Almost all outmigrating hatchery-reared chinook salmon are carriers of *R. salmoninarum*, which is suspected to be a significant cause of mortality after the fish enter sea water.

## METHODS

**Review of existing literature concerning the effects of collection, handling, and transportation on salmonid fish (objective 1).**

Our method is to collect information from both the published and "gray" literature. Particularly, we are putting special emphasis on collecting information that may not be easily available. This work is still in progress, but is scheduled to be completed by April 1993.

**Physiological assays and performance indices (objectives 2 and 3)**

A number of physiological and performance measurements were used during this year's work and are described here.

### **Blood collection and measurement of plasma variables.**

Blood plasma samples were collected from fish that were quickly dipnetted and placed into a bucket containing 200 mg/l tricane methanesulfonate (MS222) buffered with 500 mg/l  $\text{NaHCO}_3$ . Length and weight, as well as the presence of fin clips was then recorded for each fish. The fish were bled by severing the caudal peduncle, after which whole blood was collected into ammonium-heparinized capillary tubes. Whole blood was centrifuged, and the plasma removed and immediately frozen on dry ice. Plasma was initially stored at  $-20^\circ\text{C}$ , but later transferred to  $-80^\circ\text{C}$ .

We measured plasma cortisol concentration as an index of stress. Plasma cortisol is a widely accepted measure of the primary (neuroendocrine) response to stress (Mazeaud et al., 1977). Thawed plasma samples were assayed for cortisol using a radioimmunoassay (Foster and Dunn, 1974) as modified for use with salmonid plasma (Redding et al., 1984).

Plasma chloride in freshwater fish typically decreases following a stressor (Mazeaud et al., 1977) and was also used as an indicator of stress. Chloride

concentration was determined in thawed plasma using a Corning 920M chloride meter.

#### **Measurement of immune function.**

Immune system function is known to change during the stress response (Maule et al., 1987) and specific immune function was evaluated using a hemolytic plaque assay that measures the antibody-producing response to a specific antigen (Tripp et al., 1987). The anterior kidney of the fish was removed, and the number of white blood cells capable of mounting an antigenic response (termed plaque-forming cells, or PFC's) was measured.

Non-specific immune function was evaluated by determining the interferon-producing capacity of leukocytes from the anterior kidney. Interferon plays an important role in stimulating cells of the immune system to respond to infection. A modification of the spectrophotometric method described by Renault et al. (1991) was used to measure interferon-producing capacity. Briefly, anterior kidney (AK) tissue was forced through a stainless steel screen and the resulting cell suspensions were centrifuged over a layer of Histopaque (density 1.077). The cells at the interface were recovered, washed, counted, and resuspended in L-15 media containing the interferon inducer polyriboninosinic:polyribocytidylic acid. After overnight culture, the cells were pelleted and 0.1 ml aliquots (replicated 6X) of the interferon-containing supernatants were diluted and transferred to 96-well tissue culture plates containing fresh monolayers of CHSE-214 cells. Following overnight culture, the supernatants were discarded and the CHSE cells challenged with IHN virus (isolate 039-82). The monolayers were cultured for 3 d, then fixed and stained with crystal violet. The extent of cell breakdown was quantified by reading the absorbance (optical density, OD) of the stained monolayers at 600 nm with an ELISA reader.



The percent protection provided by treatment of the CHSE cells with each dilution of AK cell supernatant was estimated as:

$$\frac{(\text{OD treated, challenged cells}) - (\text{OD untreated, challenged cells})}{(\text{OD treated, unchallenged cells}) - (\text{OD untreated, challenged cells})}$$

Percent protection was plotted against dilution and the dilution providing 50% protection estimated by extrapolation. Interferon activity in tissue culture protective units ml<sup>-1</sup> (TCPU-50 ml<sup>-1</sup>) was then estimated as: (1.0 ml/0.1 ml) X (reciprocal of dilution providing 50% protection).

In addition, we recovered buffy coat cells from centrifuged blood samples to determine the number and composition of white blood cells (WBC) in peripheral blood. The WBC were suspended in 50 ul of chinook salmon plasma and 5 ul subsamples were smeared on glass slides or transferred to 1 ml of Dacie's fluid (10 ml formalin, 31.3 g trisodium citrate, and 1.0 g brilliant cresyl blue liter<sup>-1</sup>). The smears were later stained with Wright's stain for microscopic determination of cell composition. The cells preserved in Dacie's fluid were counted in a hemocytometer to permit calculation of the total number of WBC per blood sample.

### Other Analyses

Degree of smoltification was estimated by measuring gill Na<sup>+</sup>/K<sup>+</sup> ATPase. Gill filaments were collected into a buffer solution (Zaugg, 1982) and frozen on dry ice. They were then stored at -20 °C for 1-3 weeks, until they could be moved to storage at -80 °C. Later, the tissue was thawed and Na<sup>+</sup>/K<sup>+</sup> ATPase measured by the method of Zaugg (1982), using the technique described in Heinonen and Lahti (1981) to measure free phosphate produced by the ATPase enzyme.

Gill samples from fish netted from the fish separator exit flumes at Little Goose dam were examined for the presence of parasites and disease. The first gill arch on the right side was excised and preserved in Bouin's solution for 24 h, then transferred to 70% ethanol for storage. After the tissue had been dehydrated and

embedded in paraffin, 8-micron sections were cut and stained in hematoxylin and eosin. The stained specimens were evaluated by John Morrison, pathologist at the Fish and Wildlife Service's Olympia Fish Health Center.

Bacterial kidney disease was measured using the technique of Rockey et al. (1991). Whole fish carcasses were frozen and stored at -20 °C. After thawing, the kidney tissue of each fish was removed, and degree of BKD infection measured using an ELISA (Enzyme-Linked Immuno-Sorbant Assay).

Swimming endurance was measured in fish collected at the Lower Granite fish facility and during barge transport. These animals were quickly dipnetted, anesthetized in MS222 (50 mg/l) buffered with 100 mg/l NaHCO<sub>3</sub>, and then loaded into 2.5 m flow-through swim tubes. They were allowed to rest within the swim tube for 15 min, with minimal flow. The flow was then increased to 20 cm/s for a period of 30 min. Finally, the water velocity was increased to approximately 60 cm/s and the time to fatigue recorded.

#### **Stress response of chinook salmon smolts held in raceways with or without large steelhead smolts (Objective 2A.1).**

Plasma cortisol and chloride was measured in chinook juveniles held in the presence or absence of large steelhead smolts. Sections of two raceways at the Little Goose facility were loaded with either fish passing through the small-fish side of the separator (63 to 94% chinook salmon smolts, the remainder steelhead smolts 150 to 200 mm in length) or with a mixture of fish from both the small-fish and large-fish sides (25 to 90% steelhead, 190 to 260 mm in length, and 10 to 75% chinook salmon). Loading of small fish was alternated between the two raceways at 1-h intervals from 1800 to 2400 h. Screens were used to limit the length of raceway used during loading to 12-20 feet; after loading was completed, fish density was adjusted by moving the screens. Raceway sections shorter than 12 feet were not used because of concern that repeated sampling from shorter sections might elicit a stress response in fish remaining in the raceway. Chinook salmon smolts were sampled (N = 16) with a

lift-net from each of the two raceways at approximately 0430 (predawn), 0830 and 1130 h. This experiment was repeated three times (May 3, 7 and 10).

**Physiological and physical condition of smolts exiting from upstream and downstream sections of the Little Goose fish separator (Objective 2A.2).**

Chinook salmon smolts were sampled individually by dip-net from the separator exit flumes at the Little Goose facility between 1600 and 2000 h on three dates (April 25, April 28 and May 2). Twenty fish were collected from each exit flume. The fish were immediately anesthetized, weighed and measured. Blood and tissue samples were taken for determination of plasma cortisol and chloride, gill  $\text{Na}^+/\text{K}^+$  ATPase, gill histology, and BKD infection level. Additional data on fish numbers, species composition, sizes, mortality and descaling were collected at the facility throughout the spring by Corps of Engineers and Oregon Department of Fish and Game personnel. These data were generously provided and explained by the COE personnel responsible for operation of the facility (Rex Baxter, manager and Rebecca Kalamsz, assistant manager).

**Recovery from stress in chinook salmon smolts held in covered and uncovered raceways following bypass passage (Objective 2B).**

Changes in plasma cortisol and chloride were measured in smolts following bypass passage at the Little Goose facility. Two raceways, one covered with plywood and the other uncovered, were loaded with chinook salmon smolts passing through the small-fish side of the separator. Loading was alternated between the two raceways at 1-h intervals between 1800 and 2400 h. Screens were used to limit the length of raceway used to 12-20 feet. Chinook salmon smolts were sampled ( $N = 16$ ) with a lift-net from each of the two raceways at approximately 0430 (predawn), 0830 and 1130 h. This experiment was performed twice (April 22 and 29).

### **Stress response of chinook salmon smolts loaded directly into barges or held in raceways (Objective 3A.1)**

Fish exiting the fish separator during nighttime hours at Lower Granite Dam were diverted either into a barge compartment or a raceway. Loading was alternated between the barge and raceway at 1-h intervals for 6 h. Plasma cortisol was measured in chinook salmon sampled ( $N = 16$ ) with a lift-net from each of the two locations at approximately 0430, 0830 and 1030 h. This experiment was repeated three times (April 17, May 10 and 16).

### **Effect of barge transportation on indices of stress (objective 3A.2)**

The physiological status of chinook salmon smolts was measured at various points during the collection and barging process (Table 1). Our goal was to locate and describe particularly stressful aspects of the collection/transportation system by measuring various clinical and performance indicators of stress. In addition, we hoped to learn if recovery from stress occurs during barging, in order to establish the health status of the fish at liberation.

We conducted these measurements three times over the course of the outmigration: 26-28 April, 4-6 May, and 16-18 May 1992. Conditions within the barges over these periods are summarized in Table 2. The sampling dates were chosen to coincide with the early, middle, and late portions of the outmigration which allowed us to measure differences in the response to transportation over the migration season.

Plasma cortisol and chloride concentrations were determined for all fish collected. In addition, immune competence, bacterial kidney disease (BKD) infection level, and gill  $\text{Na}^+/\text{K}^+$  ATPase were measured in the samples collected from the Lower Granite gatewell, fish facility (before barge loading), and from the barge at Bonneville Dam (shortly before release). Scales were also collected from individuals in these three samples and archived for future reference.

White blood cell counts and interferon-producing capabilities were

**Table 1:** List of locations from which juvenile spring chinook were collected during the 1992 evaluation of barge transportation. During each run, 24 fish were taken at each of the points listed below. In samples collected during barge transport, 12 fish were taken from each of the stern holds (starboard and port).

---

- 1) Lower Granite Dam gateway
- 2) Lower Granite fish facility (fish were collected in the flume, downstream of the separator)
- 3) After loading on barge but before departure from dam (approximately 8h after loading of barge began)
- 4) On the barge "Chinook" (8000 series), 2 h after departure from Lower Granite Dam.
- 5) On the barge "Chinook", immediately after passage through the Lower Monumental Dam lock
- 6) On the barge "Chinook", 1h after reaching the confluence of the Snake and Columbia rivers
- 7) On the barge "Chinook", noon of the following day (approximately 24h after departing from Lower Granite)
- 8) On the barge "Chinook", shortly before arrival at Bonneville Dam (approximately 1.5-2.5 h before release)

**Table 2.** Description of conditions aboard the barge "Chinook" during the 1992 outmigration. Data is given for the three downstream trips from which juvenile chinook salmon were collected to measure the stress response to transportation. Samples were collected from the stern barge holds only. All fish in these compartments were collected at Lower Granite dam and loaded directly from the bypass and collection system (not held in raceways before loading).

| <b>Trip Dates</b>                                       | <b>26-29 April</b> | <b>4-6 May</b> | <b>16-19 May</b> |
|---|--------------------|----------------|------------------|
| <b>Loading (lbs. fish)</b>                              |                    |                |                  |
| Port stern hold   | 4,021              | 11,793         | 3,485            |
| starboard stern hold                                    | 2,258              | 11,788         | 6,739            |
| <b>Loading (# of fish)</b>                              |                    |                |                  |
| port stern hold   | 46,889             | 66,042         | 21,260           |
| starboard stern hold                                    | 26,329             | 66,884         | 41,110           |
| <b>Loading Density (lbs/gal)</b>                        |                    |                |                  |
| port stern hold   | 0.16               | 0.47           | 0.14             |
| starboard stern hold                                    | 0.09               | 0.47           | 0.27             |
| <b>Approx. Percent Chinook<br/>(of total # of fish)</b> | 69 %               | 16%            | 11%              |
| <b>Chinook Mortalities</b>                              |                    |                |                  |
| port stern hold   | 69                 | 152            | 17               |
| starboard stern hold                                    | 20                 | 170            | 26               |
| <b>Temperature Range (°C)</b>                           | 11-13              | 13-14          | 13-14            |
| <b>Dissolved O<sub>2</sub> Range (ppm)</b>              |                    |                |                  |
| port stern hold   | 10.0-11.6          | 9.1-10.4       | 9.8-10.4         |
| starboard stern hold                                    | 11.4-12.7          | 9.3-10.2       | 9.9-10.2         |

determined for fish collected from the Lower Granite gatewell, raceway and a barge compartment on May 16 and 17.

We also measured swimming endurance in samples of 4 fish collected from the Lower Granite Fish Facility and from the barge at Bonneville Dam. Due to technical problems, swimming endurance was measured only on fish of the last date.

Coded-wire tags were collected and analyzed in animals with a clipped adipose fin. The heads of these fish were frozen, and later sent to Mr. Bill Murray (Oregon Department of Fish and Wildlife, Clackamas, Oregon) for retrieval and decoding of the tag.

We also established a method for recapture of liberated fish to use next year in determining the post-release stress response of juvenile chinook salmon. This method consists of fishing a 1 m square net cage from the bow of the barge as the fish are released. Using this technique we were able to catch 70-100 of the released individuals (mixed chinook and steelhead). With further refinements we believe we can capture the numbers of chinook required for physiological sampling.

#### **Fish behavior during barge transportation (objective 3B.1)**

An underwater video system was used to monitor fish behavior on the barge during loading, transport, and release. This system consisted of a Micro-SeaCam MSC-100 underwater video camera (DeepSea Power & Light, San Diego, California), a black and white portable television set (acting as a monitor), and a VHS video-recorder (VCR). The television and VCR were placed in the storage room on the barge to avoid contact with moisture, while the camera was mounted on a boom and manually moved through the barge compartment.

Behavior of fish was taped on the barge "Chinook" during the downstream trip made on April 27-29, 1992. Filming was conducted during the daytime, at night, and at dusk. In addition, loading of fish at Little Goose and McNary dams, as well as the fish release were recorded. An auxiliary light source (Multi-SeaLite, DeepSea

Power & Light) was used for the night filming.

Highlights from the filming were later edited into a short tape documenting conditions within the barge compartments during the course of transportation.

### **Behavior of migrants post-release (objective 3B.2)**

The immediate post-release behavior of chinook and steelhead juveniles was documented using radiotelemetry. Radio transmitters purchased from LOTEK Engineering (Aurora, Ontario, Canada) were implanted into juvenile fish prior to loading on the barge. The transmitters operated on the 148-149 megahertz bandwidth, weighed approximately 3.3g in air, and were designed to transmit continuously for 18 days. These transmitters were larger than had been promised by the manufacturer, and their large size limited us to tagging fish 17 cm in fork length or greater. On a number of occasions chinook of this size were not available, so we substituted steelhead trout as the test animals.

Fish were collected from the separator at Lower Granite dam and anesthetized in 50 mg/l MS222 buffered with 100 mg/l  $\text{NaHCO}_3$ , after which the transmitter was implanted into the stomach (Ward and Miller, 1988). Following tagging, the fish were placed in live wells secured in the stern barge holds and allowed to recover. The animals were kept in the live wells for 24 h to allow us to monitor for regurgitation of the transmitters or other problems. At the end of this period, the tagged fish were released into the barge hold to make the downstream trip. A more detailed description of the circumstances of each release of radiotagged fish is contained in Table 3.

After release from the barge, the movements of individual fish were monitored using a LOTEK SRX400 radio receiver. A crew working from a boat determined the location of each fish at various times, and recorded this information on a map of the area. In so far as possible, we tried to obtain similar numbers of "fixes" (location and time) for each fish in the sample. Fish movements were recorded from the release site (generally near the Skamania Light - Columbia River



Table 3. Description of releases of radiotagged juvenile salmonids from the barge "Chinook" during the 1992 outmigration.

| Date of Release  | 23 April           | 6 May             | 13 May            | 19 May            | 25 May               |
|--|--------------------|-------------------|-------------------|-------------------|----------------------|
| Species  | chinook            | steelhead         | steelhead         | chinook           | chinook<br>steelhead |
| Fork Length (cm)<br>average<br>range                           | 19.6<br>18.5-21.6  | 19.1<br>17.8-19.9 | 19.5<br>18.8-20.0 | 17.8<br>17.1-18.8 | 20.3<br>19.3-20.7    |
| Weight (g)<br>average<br>range                                 | 80.3<br>64.9-103.9 | 65.6<br>60.7-74.1 | 64.8<br>54.9-70.6 | 54.0<br>43.3-59.6 | 69.2<br>59.8-81.9    |
| No. Tagged Fish Released                                       | 4                  | 6                 | 5                 | 4                 | 8                    |
| No. Tagged Fish Located<br>Post-Release                        | 3                  | 3                 | 5                 | 3                 | 7                    |
| Release Location<br>(Columbia River mile)                      | 139.0              | 139.3             | 139.4             | 140.7             | 139.5                |
| Time of Release (hrs)  | 0103               | 2117              | 0105              | 0215              | 0024                 |
| River Discharge at Bonneville<br>Dam at Time of Release (kcfs) | 190                | 220               | 233               | 216               | 210                  |

mile 139.5) to a site about 11 miles downstream (Rooster Rock - river mile 128.7). The information gained in this process allowed us to estimate the speed of downstream travel for each fish, as well as the route of its movements.

In addition, we obtained data on the distribution of squawfish within our study area from Mr. Tom Poe of the Cook Field Station of the National Fisheries Research Center-Seattle (USFWS). These data were collected as part of an ongoing predator indexing study.

## RESULTS AND DISCUSSION

### **Stress response of chinook salmon smolts held in raceways with or without large steelhead smolts (Objective 2A.1).**

Plasma cortisol concentrations in chinook salmon smolts held with large (>200 mm) steelhead smolts in raceways at the Little Goose facility did not differ significantly from concentrations in chinook salmon smolts held without large steelhead (Figure 1;  $P = 0.49$ , ANOVA). The data were highly variable, with mean cortisol concentrations in the two groups differing by up to 100 ng ml<sup>-1</sup>, but no consistent pattern was evident. Plasma chloride was lower in salmon held with large steelhead (106.8 vs. 110.0 MEq ml<sup>-1</sup>), but the difference was not quite significant ( $P = 0.08$ , ANOVA). Some differences between the two groups were expected, because sampling of chinook salmon smolts exiting the separator indicated that cortisol concentrations were higher and chloride concentrations lower in smolts passing through the large-fish side than in smolts passing through the small-fish side (see following section). The chinook-with-large steelhead samples included some fish that passed through both sides of the separator, but the chinook-without-large steelhead samples were made up only of fish passing through the small-fish side of the separator.

In raceways receiving both large and small fish, the species composition ranged from 29 to 68% steelhead (Table 4) with the majority of steelhead in the 200 to 260 mm length range.

Raceways receiving only small fish contained 6 to 37% steelhead, with most steelhead in the 150 to 200 mm length range. Loading densities were low, ranging from 0.04 to 0.08 lb./gallon, or about 8 to 16% of the maximum allowable loading. Too few fish exited the separator during the 3 or 4 h raceway loading period to allow higher densities to be attained (screens were used to adjust loading densities, but raceway sections less than 12 ft. in length were not used). The loading period will be extended and the effect of higher densities tested in 1993.

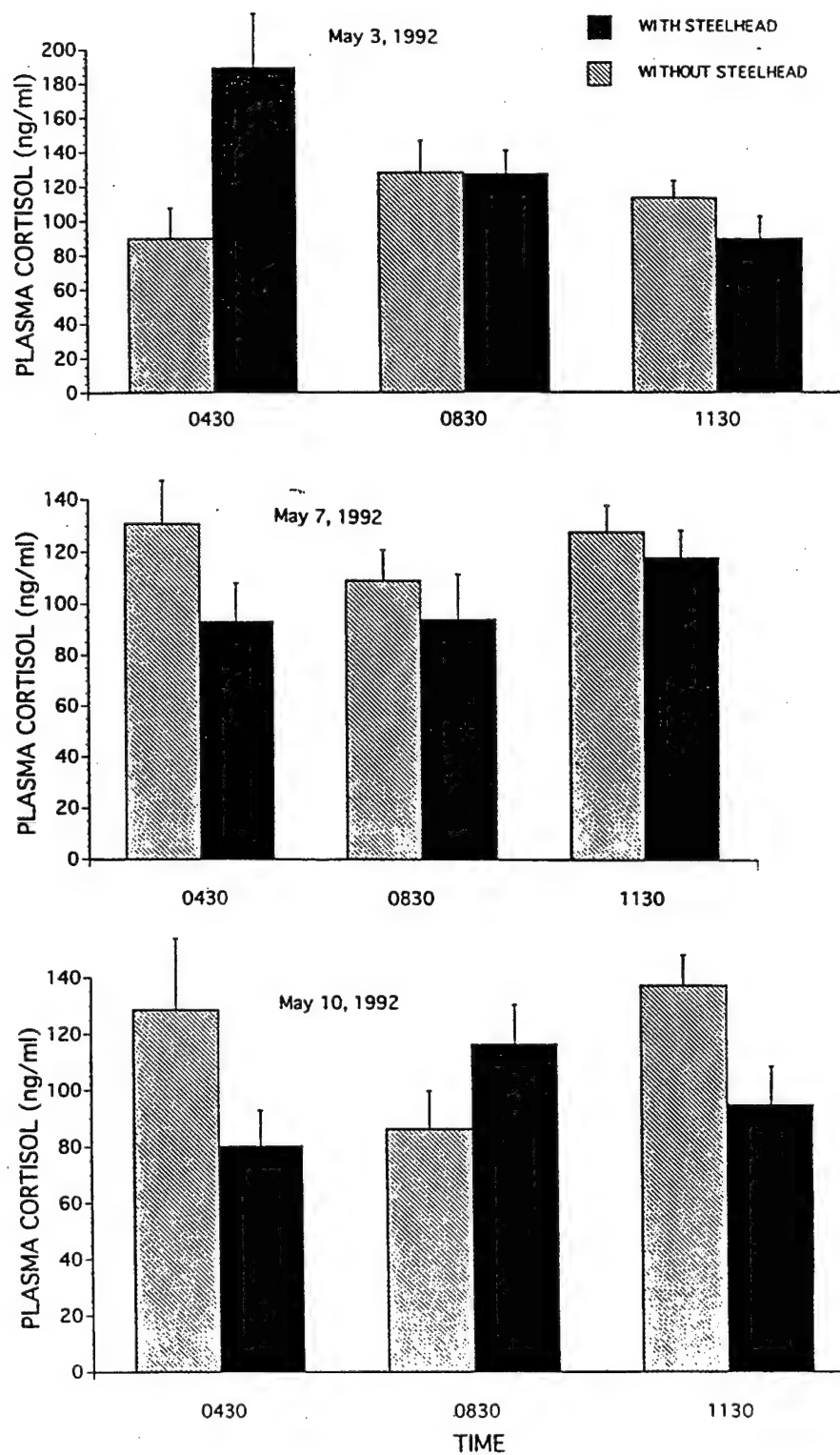


Figure 1. Plasma cortisol concentrations (ng/ml; mean  $\pm$  SE) in chinook salmon smolts ( $N = 16$ ) held in raceways with or without large steelhead smolts. Trials were performed at the Little Goose facility on three dates (May 3, upper; May 7, middle; May 10, lower) in 1992.

Table 4. Species interaction trials at Little Goose facility (1992): raceways and loading densities (lbs fish/gallon), ratios of fish from small-fish and large-fish sections of separator (applicable to mixed large-fish and small-fish raceway only), and species composition (percent steelhead).

| <u>Date</u> | <u>Mixed Large and Small</u> |                |              |              | <u>Small only</u> |                |                | <u>Large only</u> |                |                  |
|-------------|------------------------------|----------------|--------------|--------------|-------------------|----------------|----------------|-------------------|----------------|------------------|
|             | <u>Raceway</u>               | <u>Loading</u> | <u>Lg:Sm</u> | <u>ratio</u> | <u>Percent</u>    | <u>Raceway</u> | <u>Loading</u> | <u>Percent</u>    | <u>Raceway</u> | <u>Percent</u>   |
|             | <u>number</u>                | <u>density</u> |              |              | <u>steelhead</u>  | <u>number</u>  | <u>density</u> | <u>steelhead</u>  | <u>number</u>  | <u>steelhead</u> |
| May 3       | 8                            | 0.06           | 1.2:1        |              | 28.9              | 4              | 0.06           | 6.4               | ----           | 42.8             |
| May 7       | 4                            | 0.08           | 1.6:1        |              | 67.6              | 8              | 0.08           | 16.7              | ----           | 74.0             |
| May 13      | 4                            | 0.05           | 1:1          |              | 64.0              | 8              | 0.04           | 36.7              | ----           | 91.3             |

**Physiological and physical condition of smolts exiting from upstream and downstream sections of the Little Goose fish separator (Objective 2A.2).**

Plasma cortisol concentrations were consistently and significantly higher ( $P = 0.05$ , ANOVA) in chinook salmon smolts exiting the downstream section of the separator (large fish section) than in smolts exiting the upstream end (Figure 2). In addition, plasma chloride concentrations were significantly lower ( $P = 0.02$ , ANOVA) in smolts exiting the downstream section (Figure 2), further confirming a greater stress response in these fish. Examination of the distribution of cortisol concentrations in the two groups (Figure 3) suggests that the higher mean concentrations in the large-fish group were due to an upward shift in the mode—that is, cortisol was somewhat elevated in all or most fish—rather than to the presence of a few fish with extremely elevated cortisol concentrations. The most likely explanation is that chinook salmon smolts delayed in the reservoir under the downstream section of the separator for a longer period of time than in the reservoir under the upstream section. This possibility will be further investigated by reviewing NMFS data on the passage of PIT-tagged fish through the Little Goose separator.

Comparison of fork length, condition factor, gill  $\text{Na}^+/\text{K}^+$  ATPase, and BKD antigen (log transformation) in the smolts exiting the two sections of the separator indicated no significant differences. A qualitative comparison of gill histology in the two groups did not indicate a difference: both groups carried several types of gill parasites (Appendix 1), but parasite loads were not exceptionally heavy. The ANOVA analyses indicated that sampling date had a significant effect on cortisol (increasing over time), chloride (decreasing over time), and condition factor (decreasing over time): these changes are consistent with increasing smoltification during the course of the outmigration.

Data on the species composition and size distribution of fish passing through the two sections of the fish separator were collected daily by facility personnel. These data indicated that 50 to 80% of chinook salmon smolts passed through the

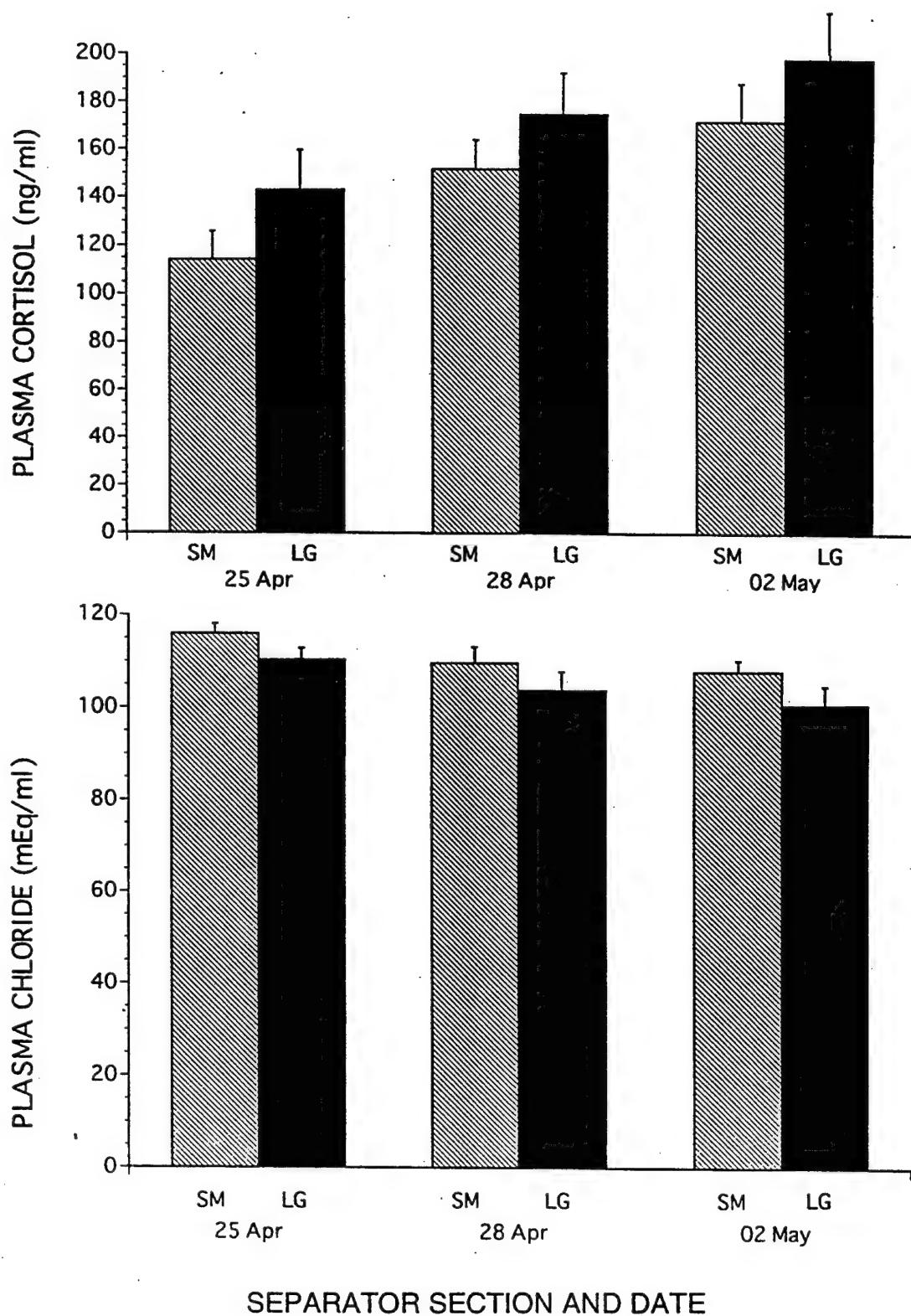


Figure 2. Plasma cortisol (mean  $\pm$  SE in ng/ml; upper) and chloride (mean  $\pm$  SE in mEq/liter; lower) concentrations in chinook salmon smolts ( $N = 16$ ) exiting from the upstream (small fish, SM) and downstream (large fish, LG) sections of the fish separator at the Little Goose facility on three dates in 1992.

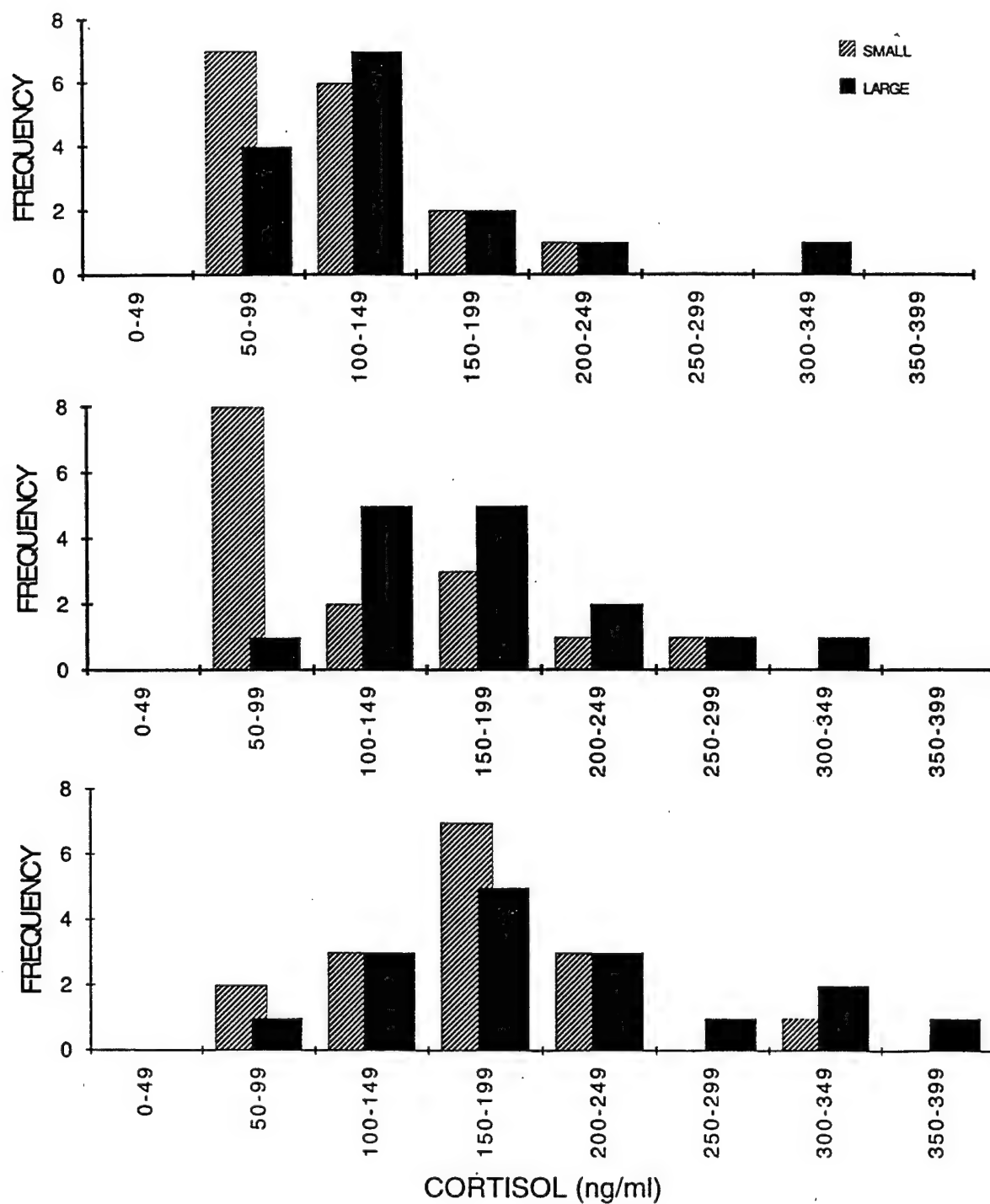


Figure 3. Frequency distribution of plasma cortisol concentrations (ng/ml) in chinook salmon smolts passing through the small-fish (hatched bars) and large-fish (solid bars) sections of the fish separator ( $N = 16$ ) at the Little Goose facility on three dates (upper, April 25; middle, April 28; lower, May 2) in 1992.



small-fish section of the separator (Figure 4). The distribution of smolts smaller than 119 mm (presumably including a relatively large proportion of wild smolts) between the upstream and downstream sections of was very similar to that of larger fish. Small percentages (7 to 20%) of hatchery steelhead passed the small-fish section of the separator; however, from 25 to 48% of the smaller wild steelhead passed through the small-fish section (Figure 4). In conclusion, the fish separator at the Little Goose facility does not separate chinook salmon and steelhead very efficiently: 20 to 50% of chinook salmon and 25 to 48% of wild steelhead pass through the "wrong" section.

Data on observed mortality of fish in the raceways and sample tanks was recorded daily by facility personnel. Mortality was generally low ( $< 0.5\%$ ) for both chinook salmon and steelhead (Figure 5), except that mortality was somewhat elevated (1.1 to 2.2%) for chinook salmon held in the large-fish raceways during the period May 11 to 31. We can not explain this observation at the present time: it occurred after the peak of both the chinook salmon and steelhead outmigrations (Figure 6), and during a period of declining numbers of [freeze-branded] hatchery fish (Figure 7). We observed no differences in the health status of chinook salmon smolts passing through the upstream and downstream sections of the separator during the earlier period of April 25 to May 2, but it may be that unhealthy fish passed through the downstream section in disproportionate numbers later in the outmigration season. This possibility will be investigated in 1993.

Descaling of chinook salmon smolts in the large-fish raceways was elevated during the week of May 11-17 (Figure 8), but not during the following weeks. Descaling of wild steelhead smolts was higher during the last three weeks in May (Figure 8), but this was not reflected in the mortality data (Figure 5) for the same period.

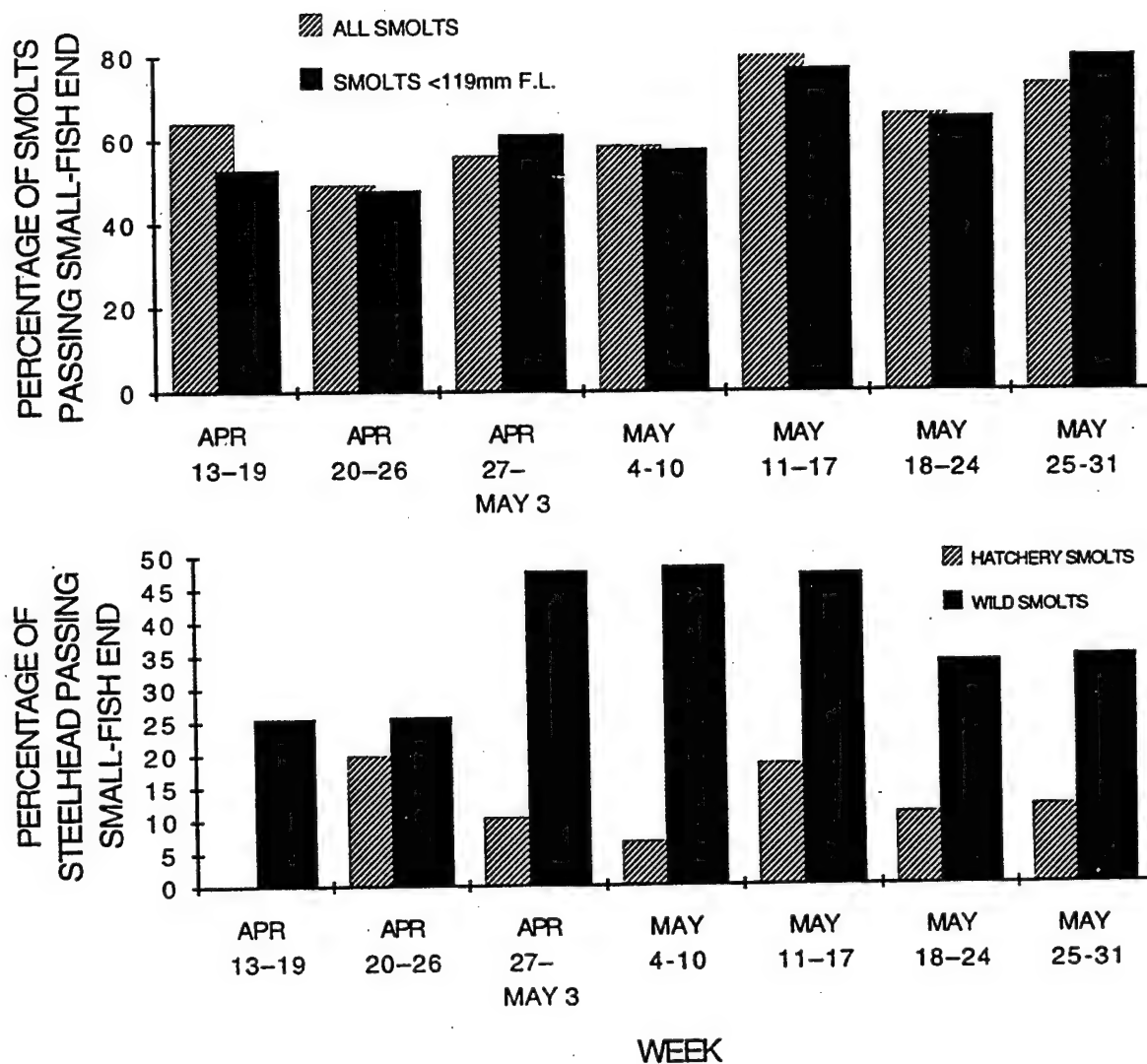


Figure 4. Percentages of chinook salmon smolts (upper: hatched bars for all smolts, solid bars for smolts <119 mm) and of wild and hatchery steelhead smolts (lower: solid bars for wild fish, hatched bars for hatchery fish) passing through the small-fish end of the fish separator at the Little Goose facility in 1992.

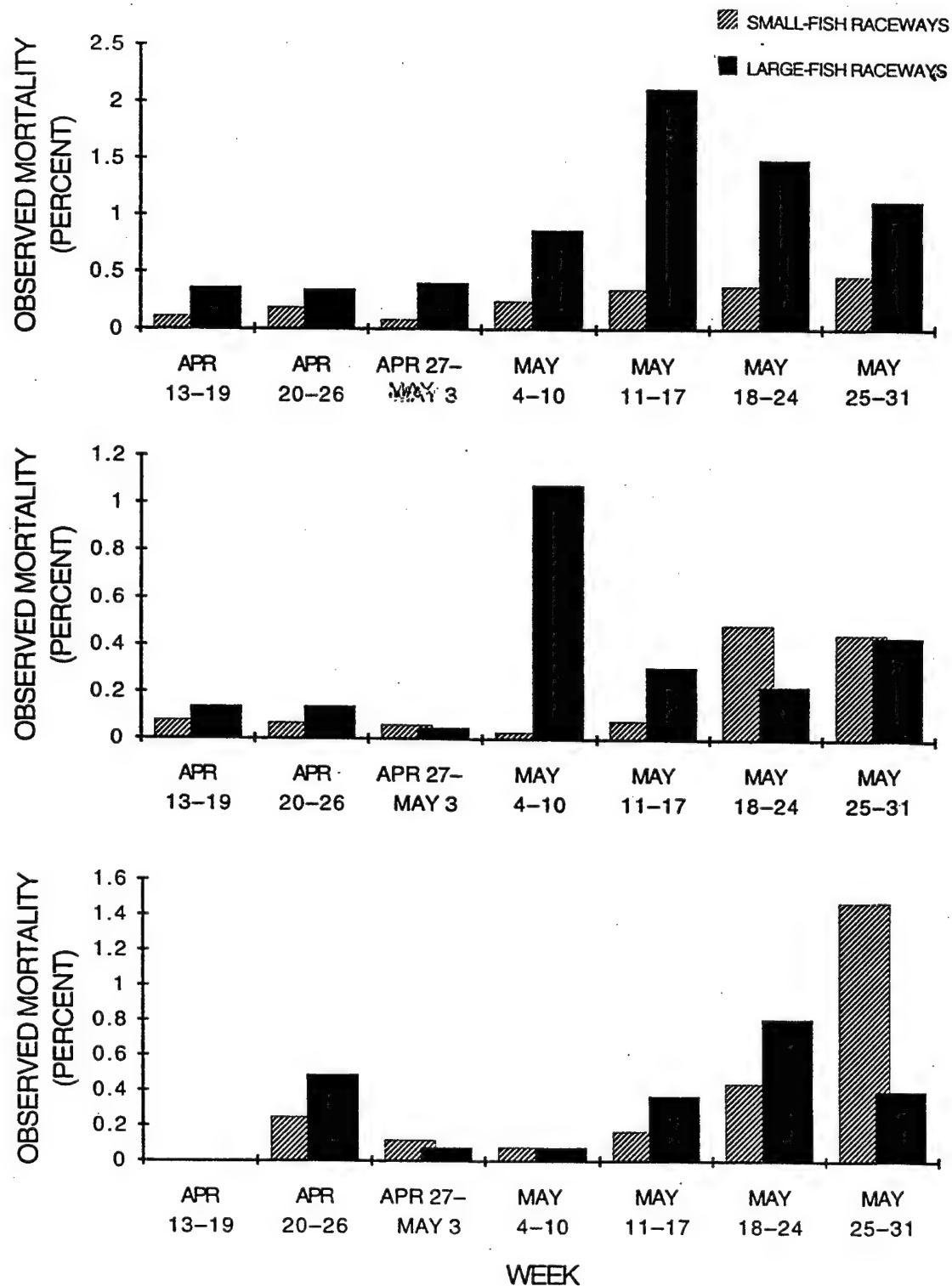


Figure 5. Observed mortality (percent) of chinook salmon smolts (upper), wild steelhead (middle), and hatchery steelhead (lower) in small-fish and large-fish raceways at the Little Goose facility in 1992.

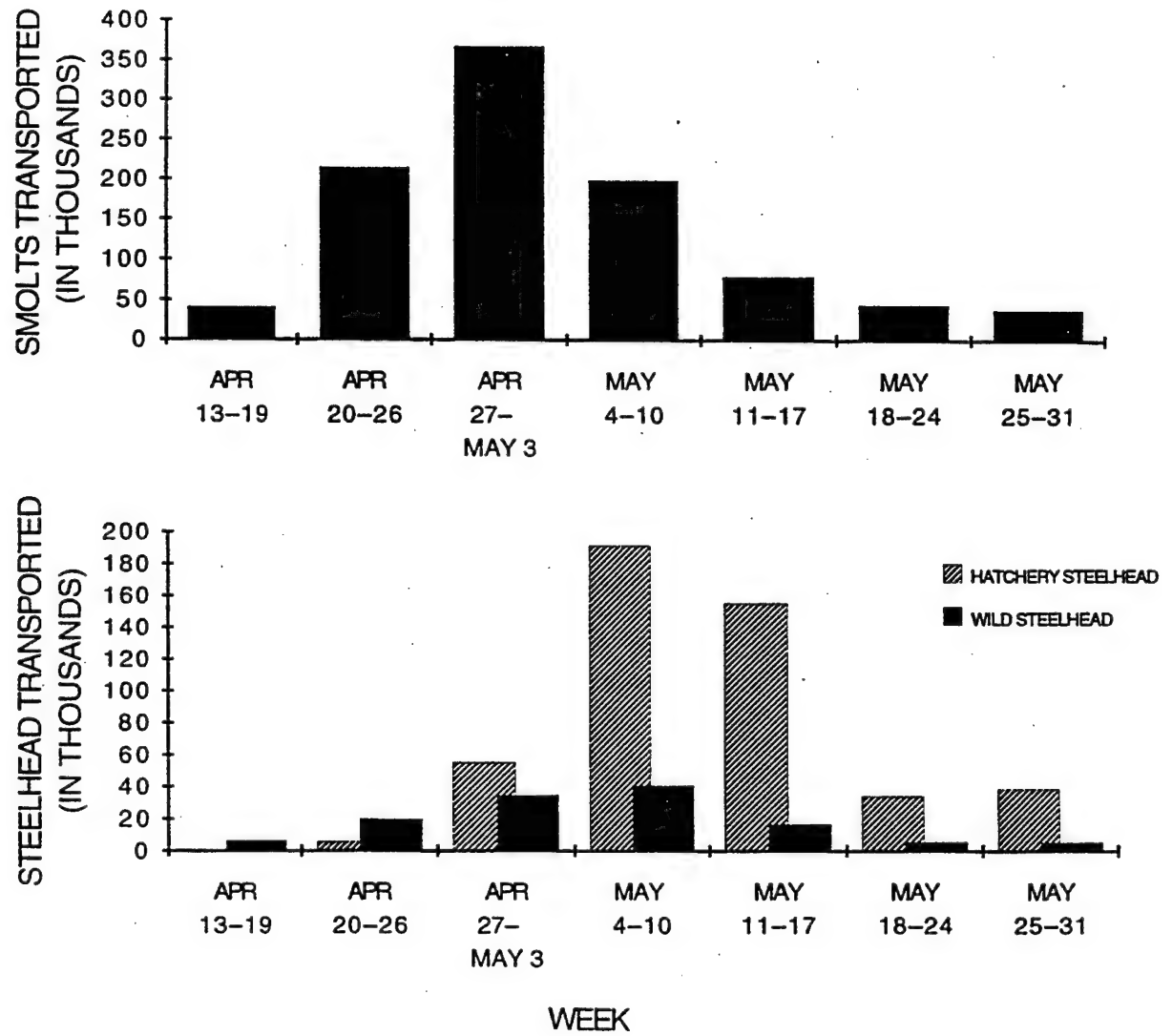


Figure 6. Number of chinook salmon smolts (upper) and wild and hatchery steelhead (lower: solid bars for wild fish, hatched bars for hatchery fish) transported from the Little Goose facility in 1992.

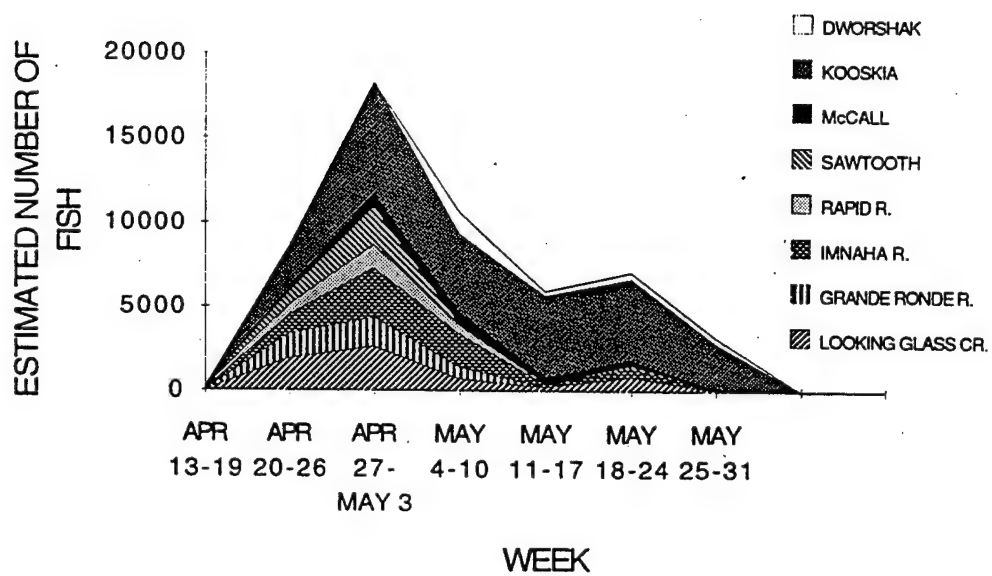


Figure 7. Estimated number of freeze-branded hatchery fish transported from the Little Goose facility each week from April 13 to May 31, 1992.

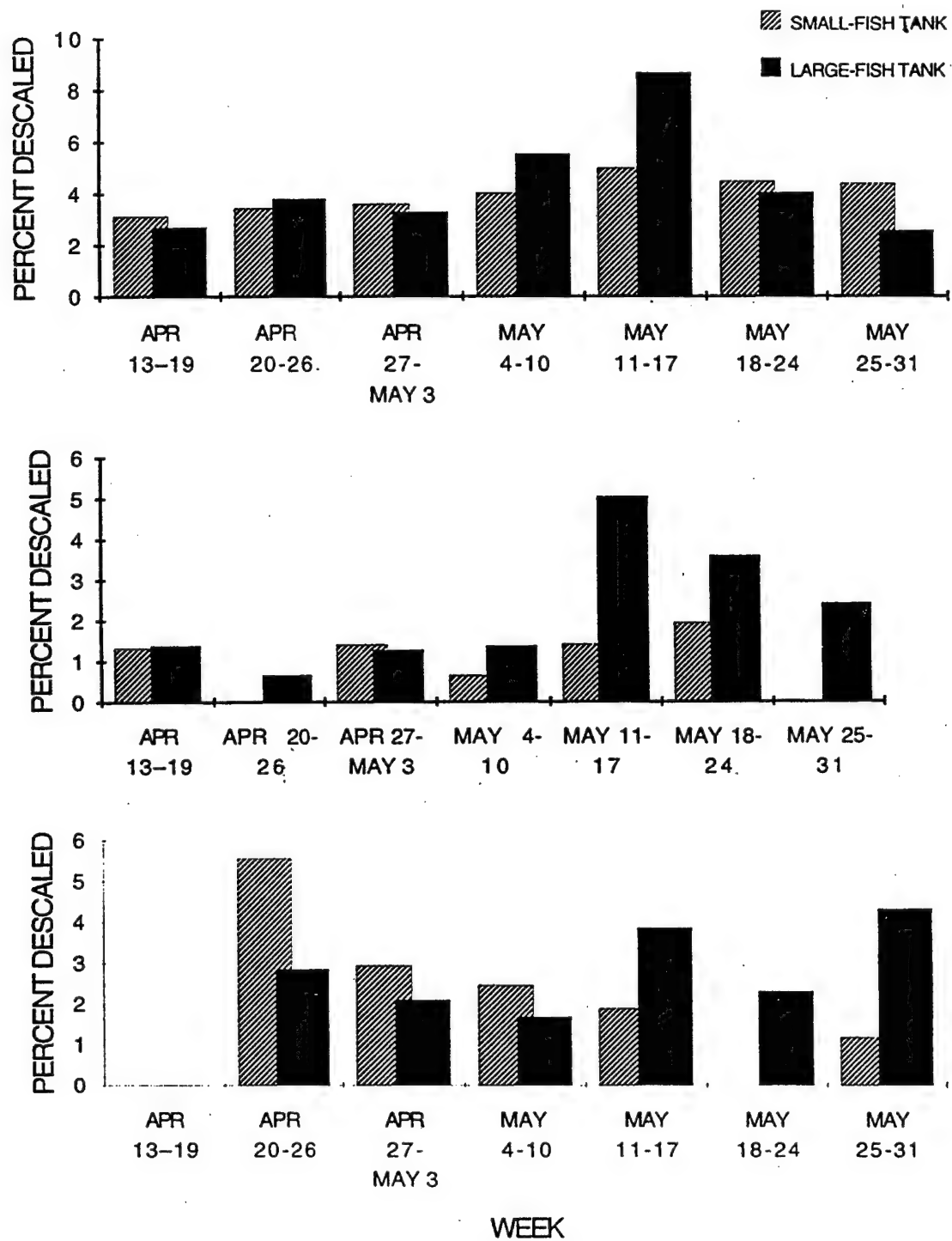


Figure 8. Descaling (percent) of chinook salmon smolts (upper), wild steelhead (middle), and hatchery steelhead (lower) in small-fish (hatched bars) and large-fish (solid bars) daily samples at the Little Goose facility in 1992.

### **Recovery from stress in chinook salmon smolts held in covered and uncovered raceways following bypass passage (Objective 2B)**

Chinook salmon smolts recovering from bypass and separator passage in covered raceways at the Little Goose facility had lower blood cortisol concentrations than smolts recovering in uncovered raceways (overall mean 76 *vs.* 105 ng ml<sup>-1</sup>, Figure 9). The difference was highly significant ( $P = 0.003$ ; ANOVA). Chloride concentrations in the two treatment groups did not differ significantly. As expected, mean fork lengths and condition factors of fish from covered and uncovered raceways were similar.

These results are consistent with an earlier report (Congleton and Wagner 1988) that the cortisol response of migrating chinook smolts to daytime flume passage was reduced under darkened conditions, and suggest that the efficacy of shading as a measure for reduction of the stress response to handling should be further investigated.

### **Stress response of chinook salmon smolts loaded directly into barges or held in raceways (Objective 3A.1).**

Plasma cortisol concentrations were lower in smolts loaded into barge compartments than in smolts loaded into raceways at the Lower Granite facility (Figure 10). The difference was highly significant ( $P = 0.015$ , ANOVA). Differences in mean cortisol concentrations between groups from the two locations were greater at the last sampling time (1030 h) than at the earlier (0430, 0830 h) times. The difference in plasma cortisol between groups was 47 ng ml<sup>-1</sup> at 1030 h, but only 15-16 ng ml<sup>-1</sup> at 0430 and 0830 h.

This work was undertaken because sampling at the lower Granite facility in 1983 (Congleton et al. 1984) indicated that cortisol concentrations were higher in chinook salmon smolts loaded directly into barge compartments than in smolts held in raceways overnight and loaded into barge compartments the following morning. This observation raised the concern that direct loading of fish onto barges

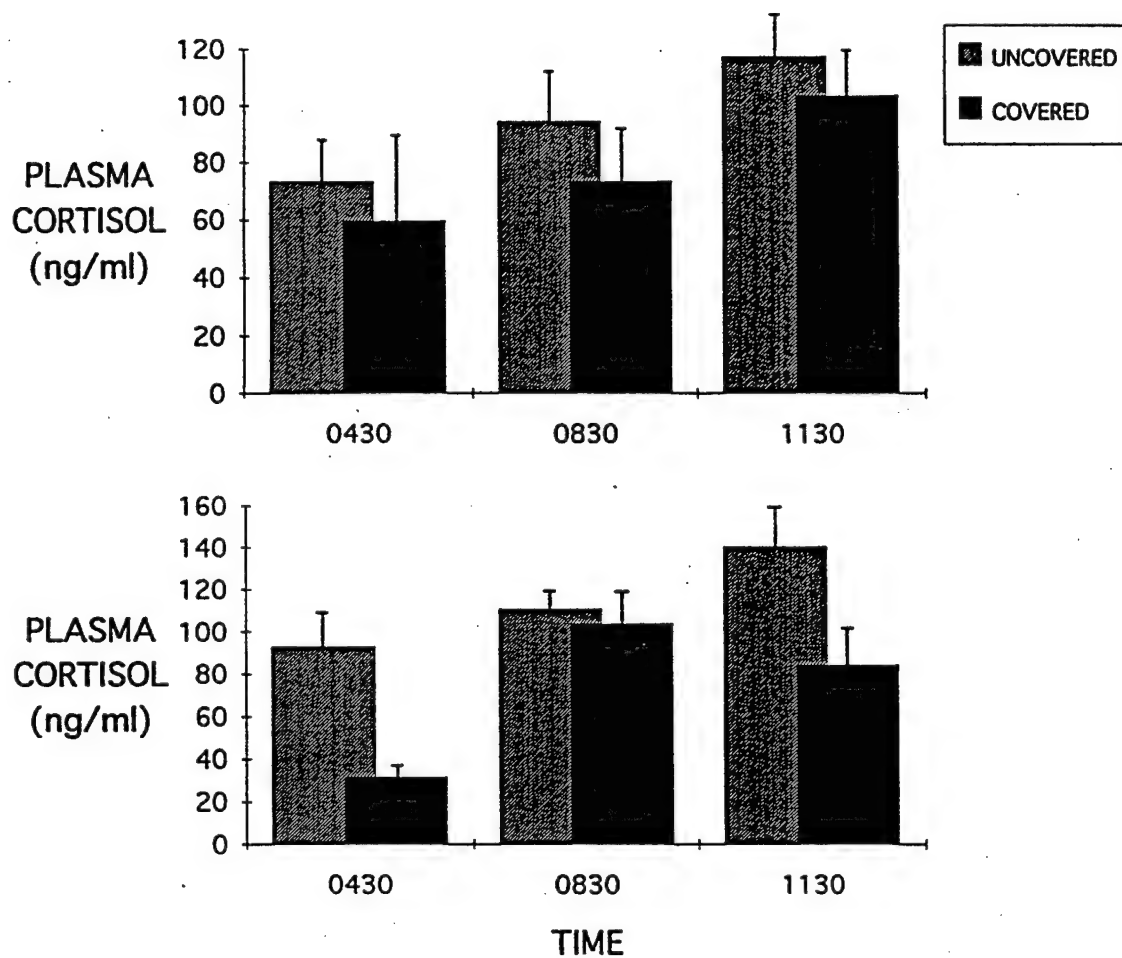


Figure 9. Plasma cortisol concentrations (ng/ml; mean  $\pm$  SE) in chinook salmon smolts ( $N = 16$ ) recovering from bypass passage in covered and uncovered raceways at the Little Goose facility. Trials were performed on two dates (upper, April 22; lower, April 29) in 1992.



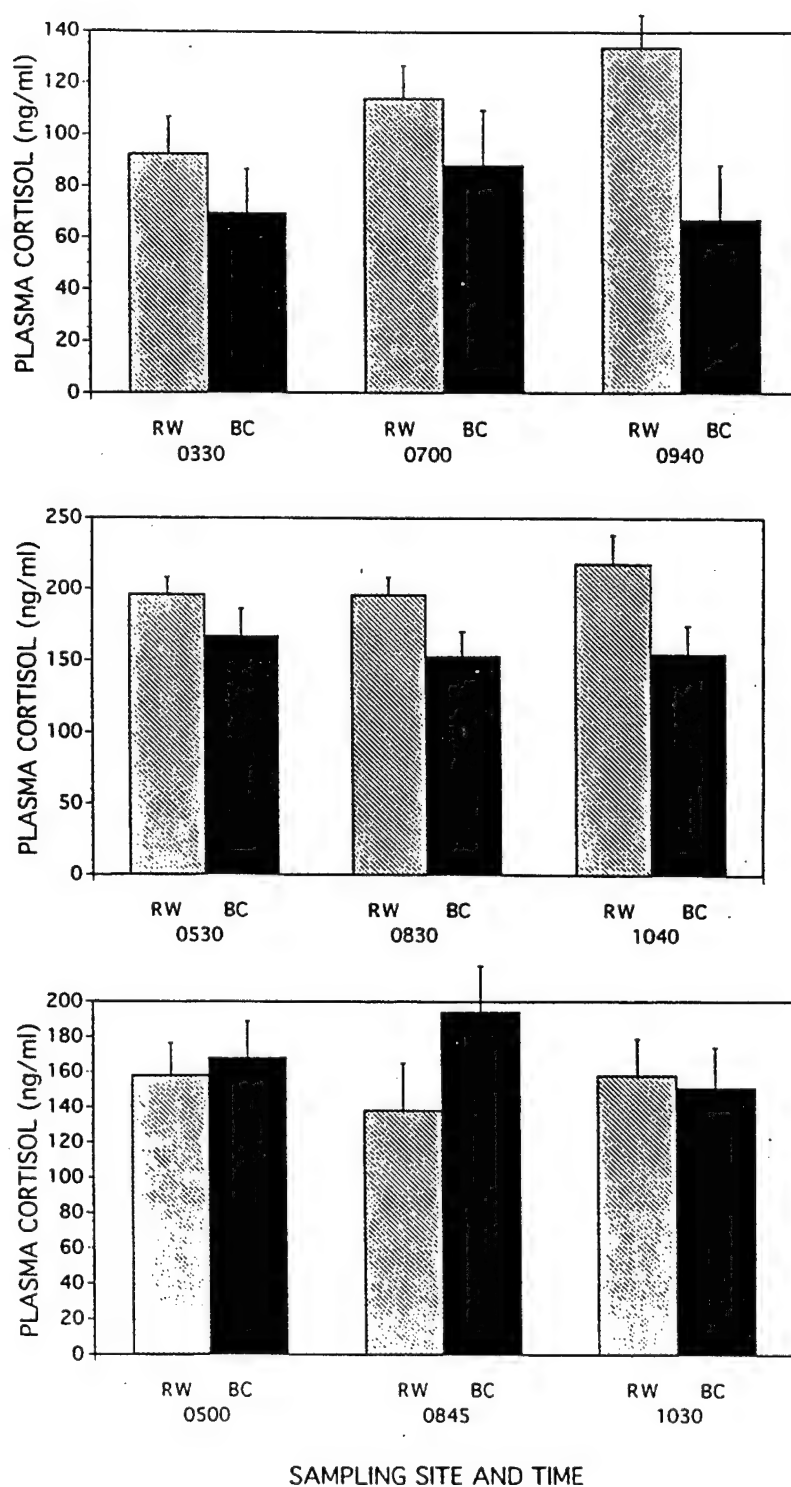


Figure 10. Plasma cortisol concentrations (ng/ml; mean  $\pm$  SE) in chinook salmon smolts (N = 16) loaded into barge compartments (BC) or raceways (RW) after exiting the bypass at Lower Granite Dam on three dates (upper, April 17; middle, May 10; lower, May 16) in 1992.

for overnight holding might be undesirable. The present results show that, contrary to the 1983 observations, barge loading and holding elicited a smaller stress response than did raceway loading and holding. In addition, cortisol concentrations rose in the raceway groups and fell in the barge groups between 0830 and 1030 h, further suggesting that the barge compartments provided better conditions for holding chinook salmon smolts than did the raceways. Barge compartments provided more shade than the uncovered raceways, and it is possible that this or some other environmental variable are responsible for the differences. The present data indicate that the current policy of direct-loading barges should be continued.

#### **Evaluation of the effect of barge transportation on indices of stress (objective 3A.2)**

Juvenile chinook salmon collected from the fish facility had significantly higher levels of plasma cortisol than fish obtained from the gateway, indicating that collection of fish at Lower Granite results in a stress response (Figure 11). This increase in cortisol was significant on all three sampling dates. Over the course of the barge trip, plasma cortisol in general declined, returning to pre-collection levels by the time of release in two of three trials. This decline was not steady, however; cortisol levels tended to fluctuate over the course of transportation (Figure 11). The cause of this fluctuation is unknown.

Mean plasma cortisol levels in samples taken from the gateway ranged from 59-75 ng/ml, which are somewhat higher than levels typical of resting salmonid smolts (Barton et al., 1985). It is possible that the fish were already moderately stressed by the time of their collection at the gateway. There were no significant difference in cortisol level between dates for either of the gateway or fish facility samples.

Plasma chloride concentration did not vary much over the course of collection and transport (Figure 12). The only differences of significance were that the fish in the gateway sample of run 1 had low values and the Bonneville sample from run 2 had high values. The average chloride concentration of the samples

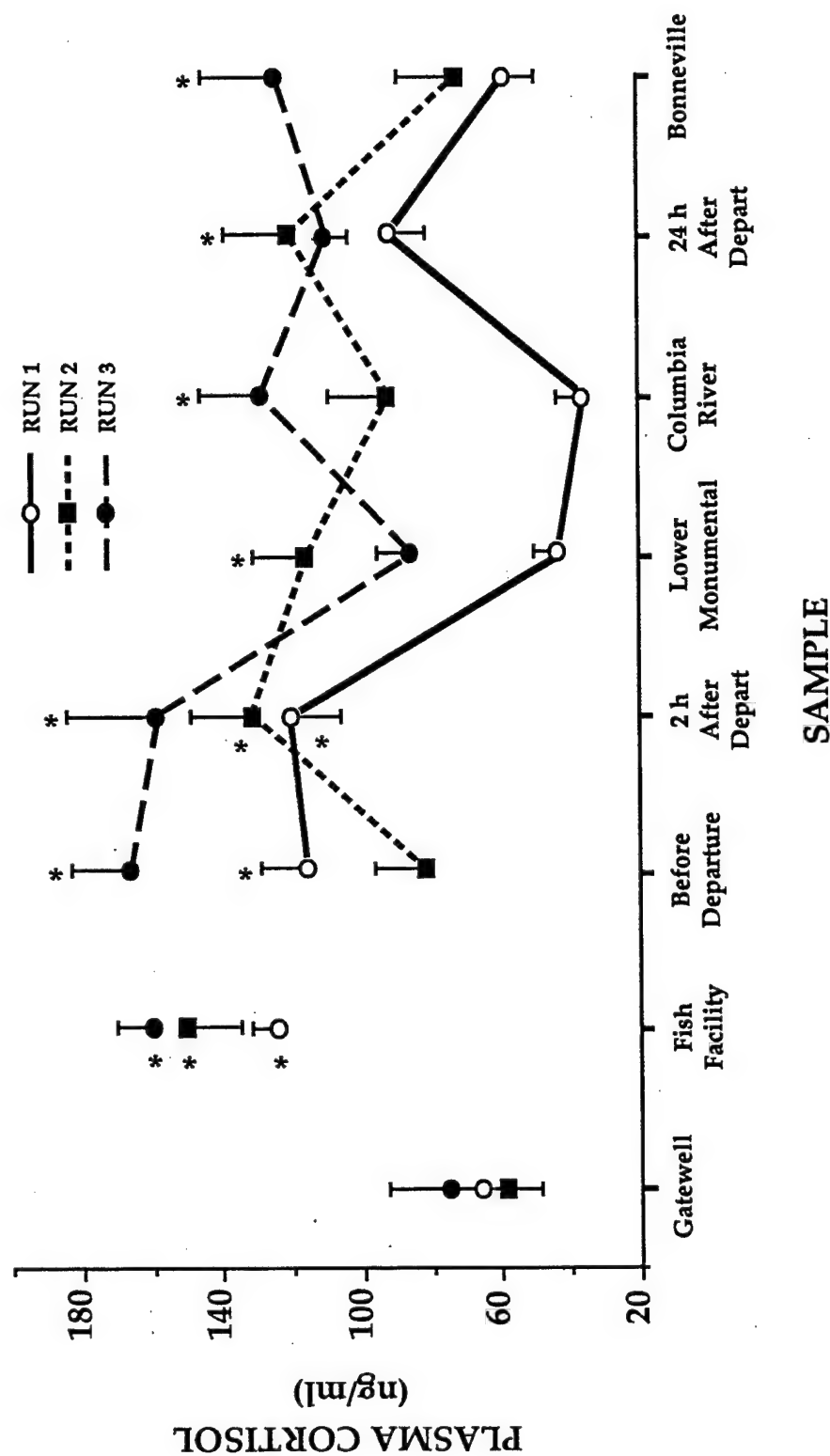
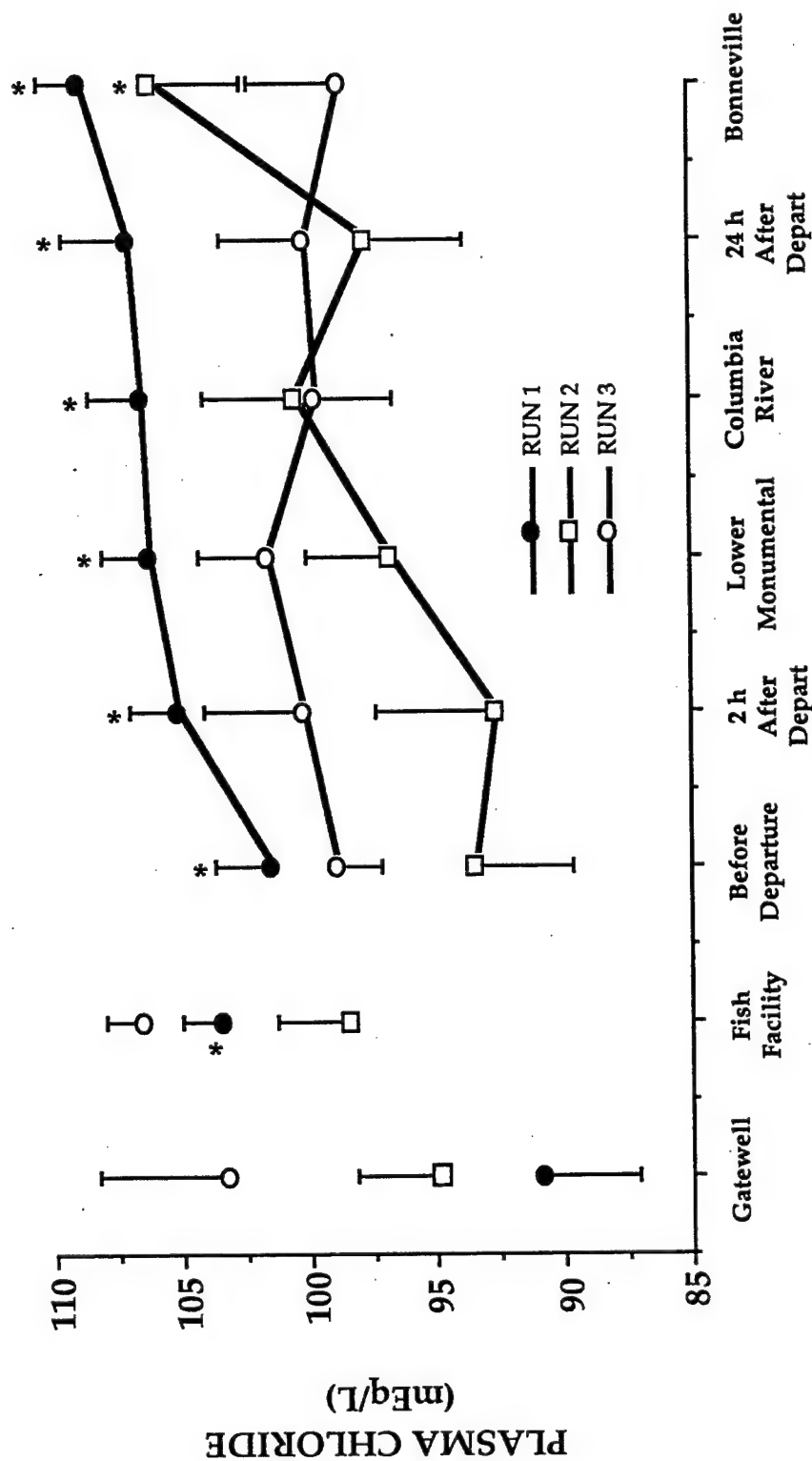


Figure 11. Plasma cortisol levels of juvenile spring chinook salmon collected from various points at Lower Granite dam and during barging. The sampling points are described in Table 1. Fish were collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3), 1992. Each point represents the mean  $\pm$  SE of 24 fish (with the exception of the gateway samples for runs two and three which contained 21 and 16 fish, respectively). Points marked with an asterisk are significantly different from the gateway sample of the same run ( $p < 0.05$ , LSD test).



### SAMPLE

Figure 12. Plasma chloride levels of juvenile spring chinook salmon collected from various points at Lower Granite dam and during barging. The sampling points are described in Table 1. Fish were collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3), 1992. Each point represents the mean  $\pm$  SE of 24 fish (with the exception of the gatewell samples for runs two and three which contained 21 and 16 fish, respectively). Points marked with an asterisk are significantly different from the gatewell sample of the same run ( $p < 0.05$ , LSD test).

ranged from 91-107 Meq/l, approximately 10% lower than typical resting values reported for steelhead (Hille, 1982). It is possible that transported chinook experience a mild osmotic imbalance.

We found a significant negative correlation between plasma cortisol and plasma chloride (Figure 13). As plasma cortisol increases, plasma chloride decreases. Plasma chloride appears to respond to stress, with the lowest chloride levels seen in the most stressed (highest cortisol) individuals.

Increased immune competence (numbers of plaque-forming lymphocytes) was observed at the end of barging, compared to fish sampled before loading (Figure 14). This difference was significant on the first and third sampling dates. Due to the oscillatory way immune competence responds to stress (Maule et al., 1989), it is difficult to determine if the immune system is recovering from the stress of collection and handling at Lower Granite, or is responding to some other previous or subsequent stressor.

Neutrophil concentrations in the peripheral blood of chinook salmon smolts sampled from raceways and barge compartments were markedly and significantly higher ( $P < 0.05$ ; ANOVA followed by Fisher's PLSD) than in peripheral blood of smolts sampled from a gatewell (Figure 15). Lymphocyte concentrations did not differ significantly in fish sampled from the three locations (Figure 15). Neutrophilia is a typical feature of the stress response in fish.

The interferon assay was still under development in the spring of 1992 and was field-tested only once. No significant difference was found in the interferon-producing capability of anterior kidney cells from fish sampled from a gatewell and a raceway.

A large majority of all fish sampled had detectable levels of BKD infection (Figure 16). Typically, 10-30% of fish had infection levels in the moderate to high range (greater than 20 ng antigen/ml kidney tissue preparation). The percentage of fish experiencing moderate to high infection increased with each subsequent sampling date (Figure 16). This level of infection may be associated with increased

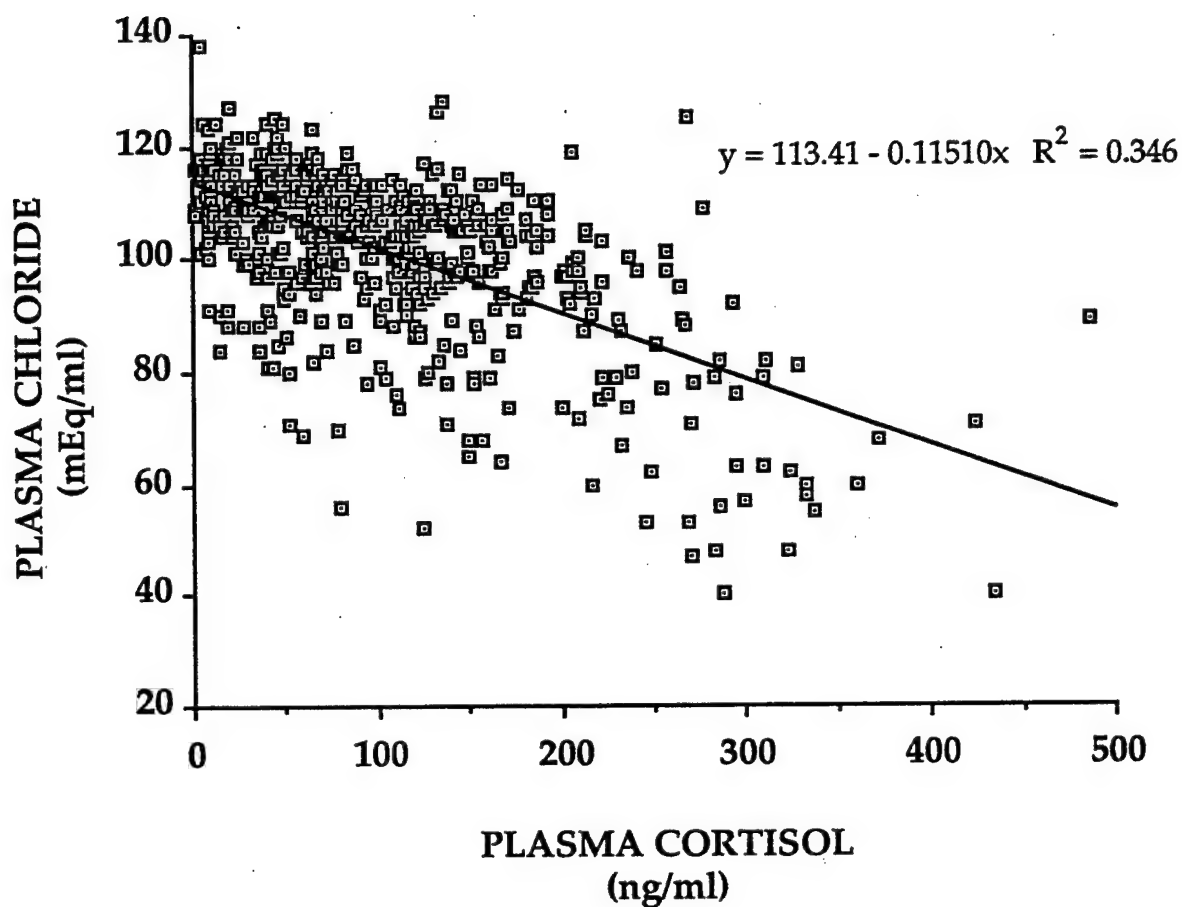
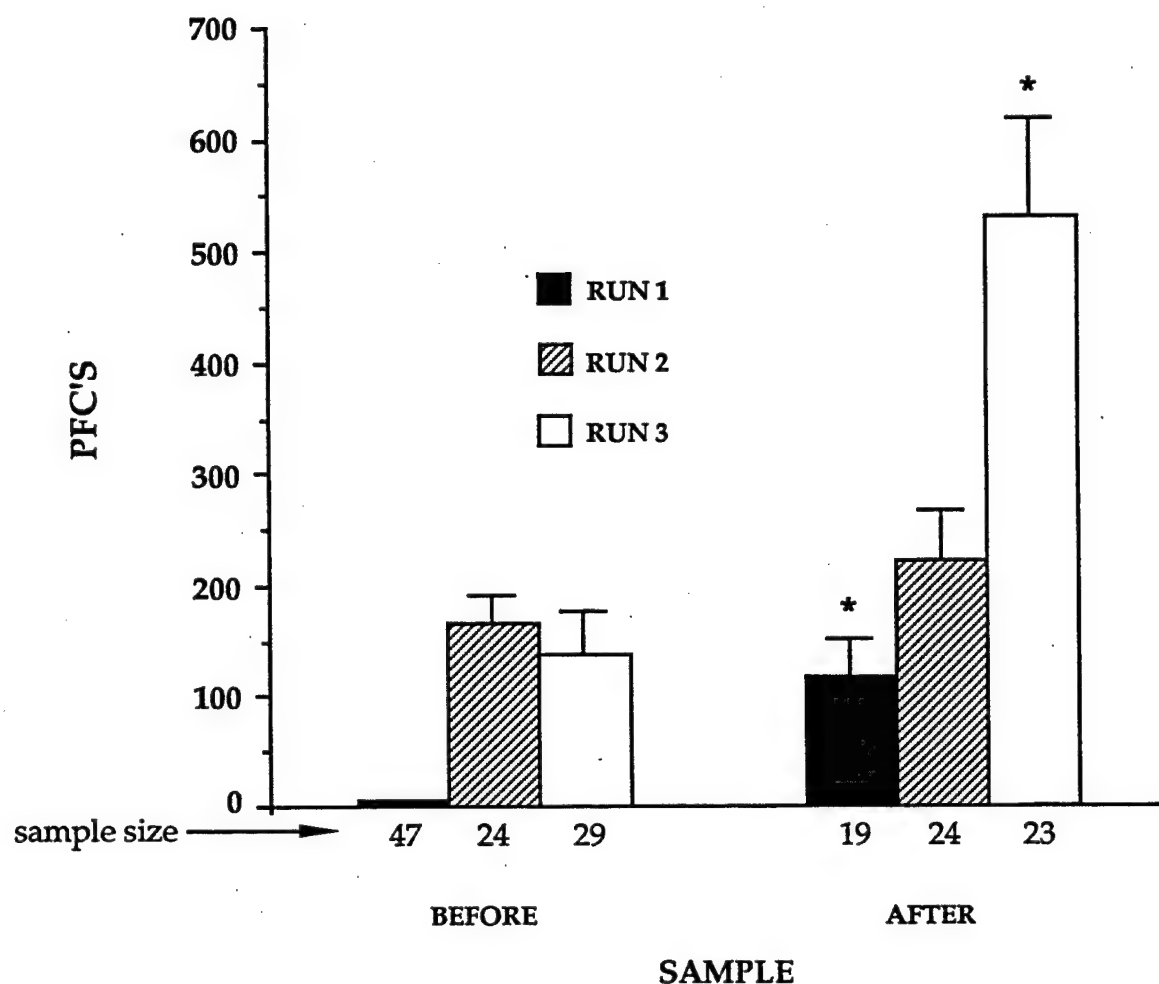


Figure 13. Linear regression of individual plasma chloride concentrations on corresponding plasma cortisol values in juvenile chinook salmon. Values from all fish collected during the 1992 field season are included (N=546). The correlation is statistically significant (that is, the slope of the line is not zero) with  $p < 0.001$ .



**Figure 4.** Numbers (mean + SE) of plaque-forming cells (PFC's) in juvenile chinook salmon before and after barging. The "before" sample is a pool of samples collected at the Lower Granite gateway and fish facility. (These samples were not significantly different from each other ( $p > 0.05$ , t-test), and were combined due to low sample sizes at the fish facility (RUN 2) and gateway (RUN 3)). The "after" sample was collected from the barge "Chinook" 1.5-2.5 h before the end of transportation. Samples were collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3). Bars marked with an asterisk are significantly different from the other sample in the same run ( $p < 0.05$ , t-test).

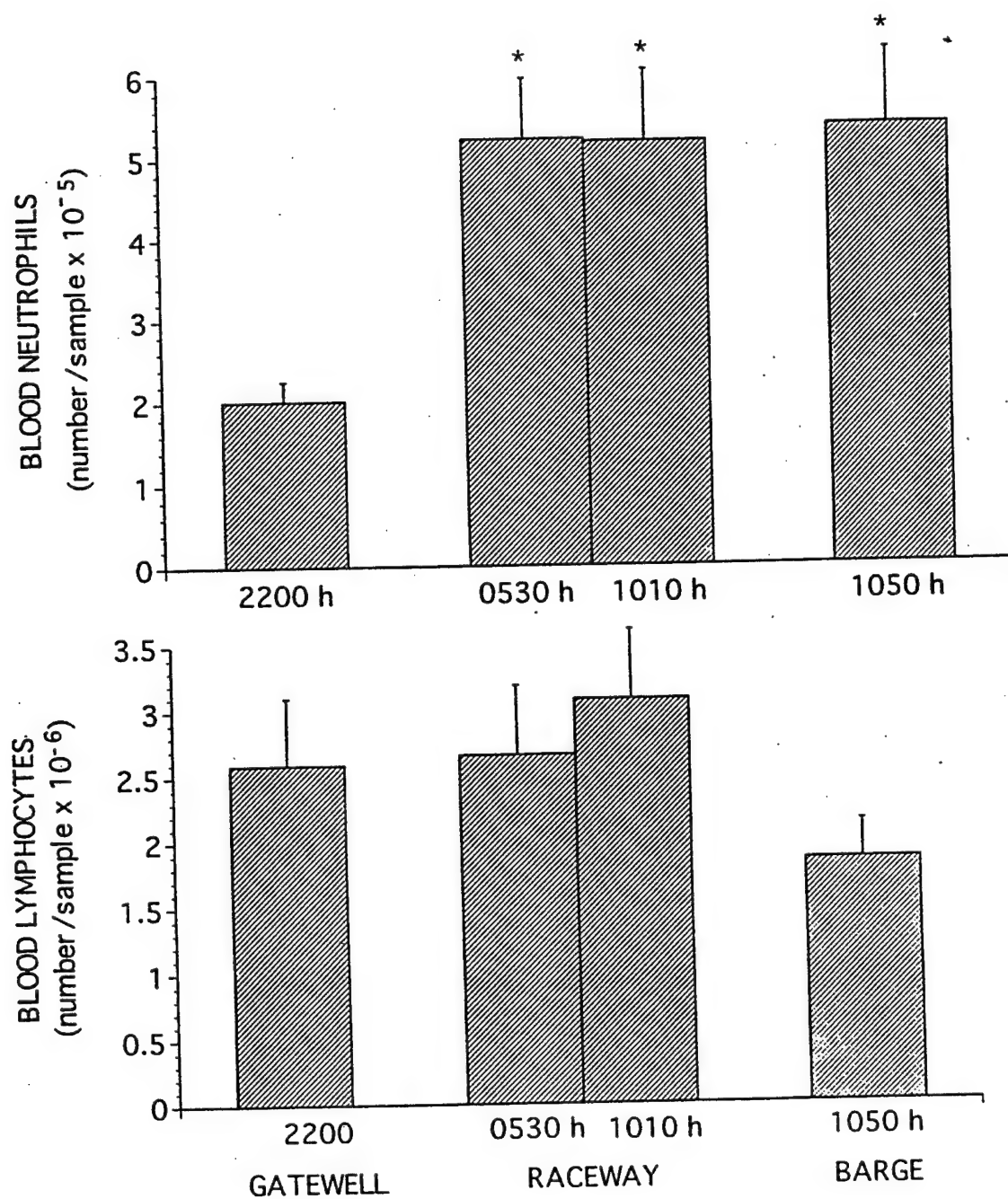
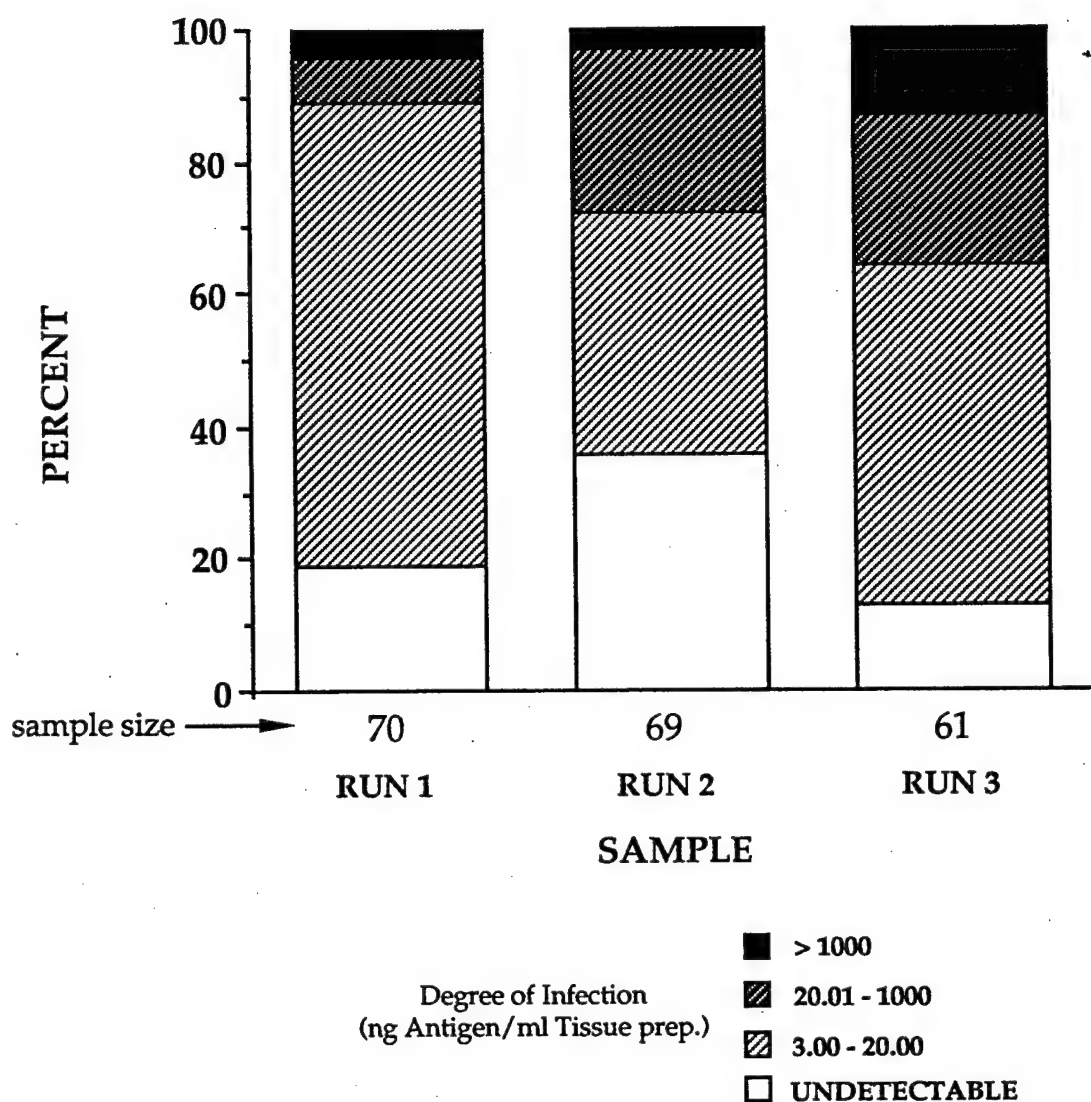


Figure 15. Neutrophil (upper) and lymphocyte (lower) concentrations (mean number/sample  $\pm$  SE) in the peripheral blood of chinook salmon smolts sampled from three locations in the collection system at Lower Granite Dam, May 16-17, 1992. Asterisks indicate means that differ significantly from the mean of the gatewell sample.





**Figure 16.** The percent of juvenile chinook salmon infected with various levels of bacterial kidney disease (BKD). Fish were collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3). Each bar represents the pooled results of three samples collected from: (1) the Lower Granite gateway, (2) the Lower Granite fish facility, and (3) from the barge "Chinook" shortly before arrival at Bonneville dam (1.5-2.5 h before release). The proportions of fish infected with each level of infection are significantly different between the runs ( $p < 0.001$ , Chi-square test).

predation risk (M. Mesa, personal communication) or decreased immune competence. We found that individuals infected with more than 20 ng antigen/ml of BKD never possessed high numbers of plaque-forming cells (immune competence) (Figure 17).

Gill  $\text{Na}^+/\text{K}^+$  ATPase increased significantly with each succeeding sampling date (Figure 18). This indicates that degree of smoltification in migrating fish increases during the outmigration season, even in fish collected at a point several hundred miles from the ocean.

Swimming endurance was measured on the last run (16-18 May). Fish sampled near the end of barging appeared to have a longer time to fatigue than fish taken from the Lower Granite fish facility (Figure 19), but this difference was not significant - probably due to small sample sizes ( $N=4$ ).

Of all fish collected, 34.9 % carried coded-wire tags. The percentage of tagged fish collected on the later two dates was nearly double the percentage collected on the first date. Information concerning coded-wire tagged individuals is summarized in Table 5.

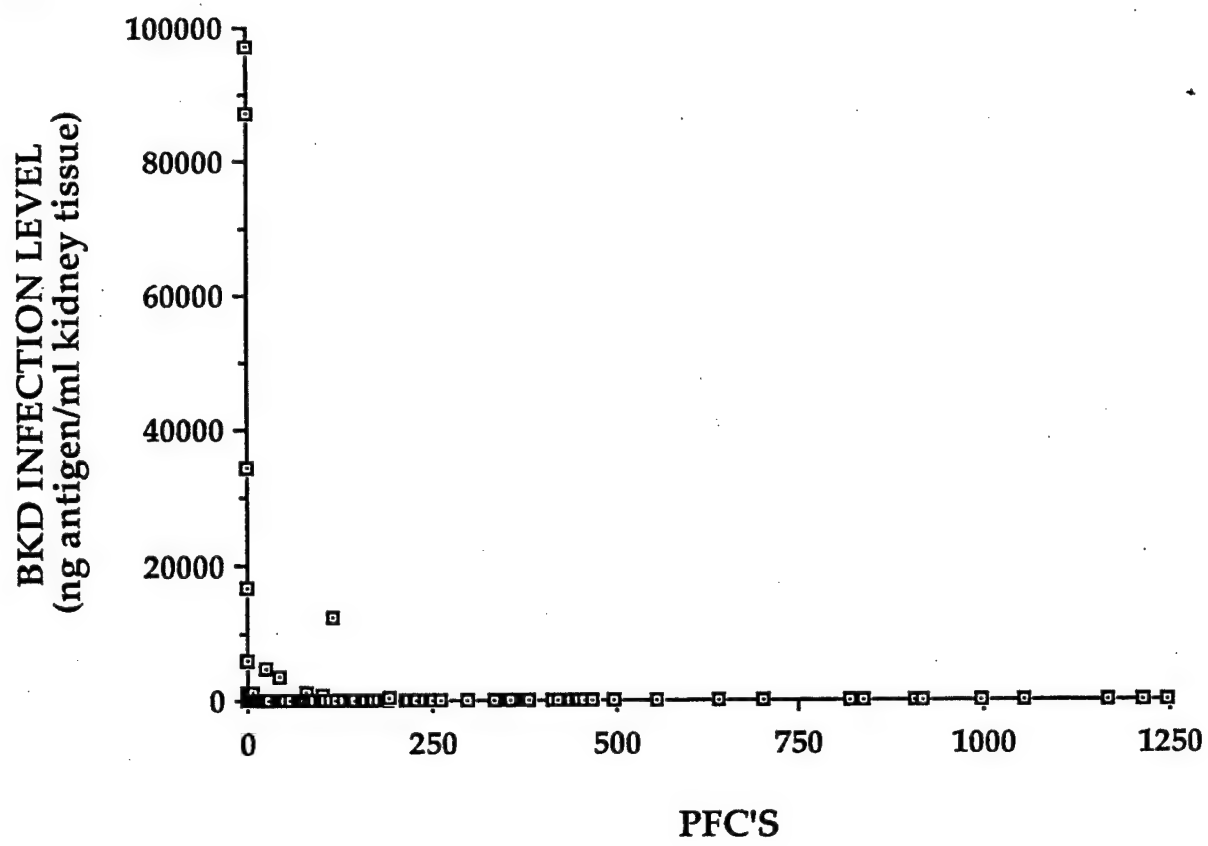
#### **Fish behavior during barge transportation (objective 3B.1)**

Behavior of fish in transport barges appeared similar to what one might expect to see in a hatchery raceway: few aggressive interactions, with many fish moving slowly around in large aggregations. Video tape of the loading procedure showed fish being discharged into the barge at high velocity, with individuals having little or no control over their movements or orientation. Although most fish swam away from the inflow plume within a few seconds, some individuals were pushed to the bottom of the barge hold (4-5 ft) before they regained control over their movements.

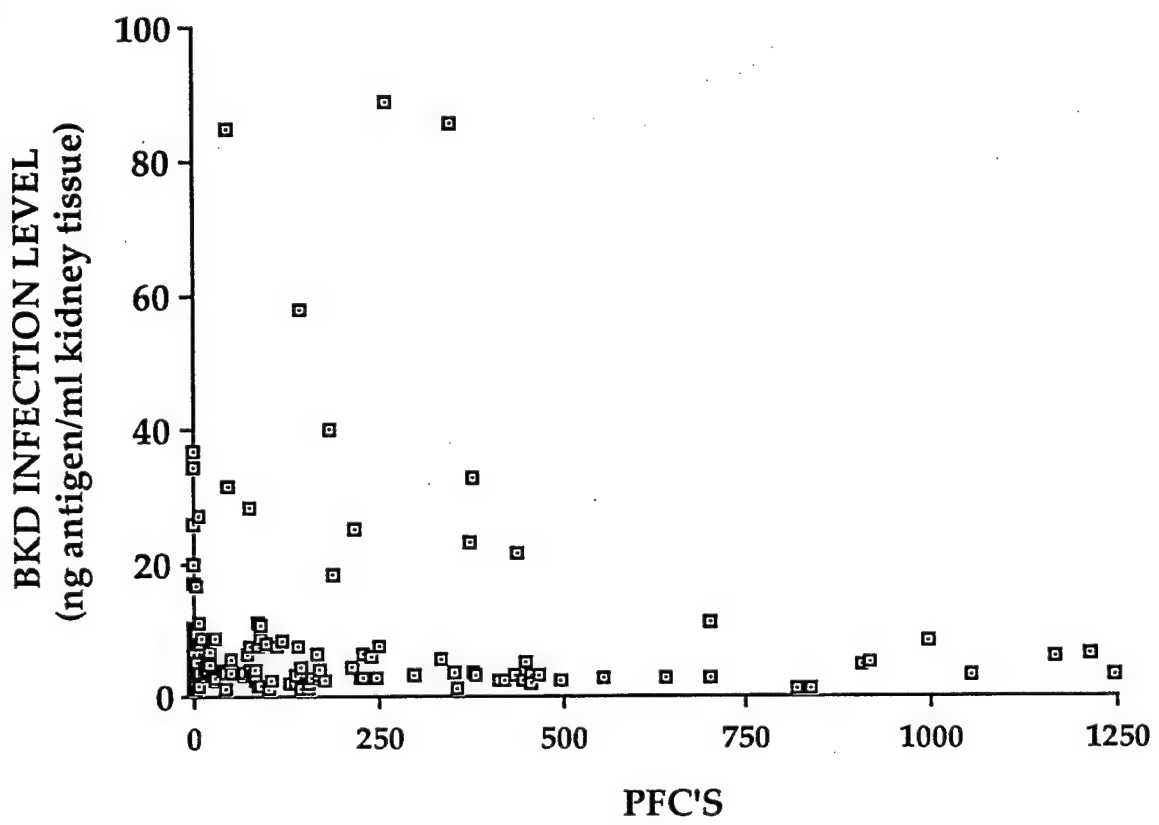
Release from the barge appears to strongly disturb the fish, and may represent a significant stressor. Many fish try to avoid being ejected through the exit hole, swimming vigorously against the outflowing current. This activity may result in an

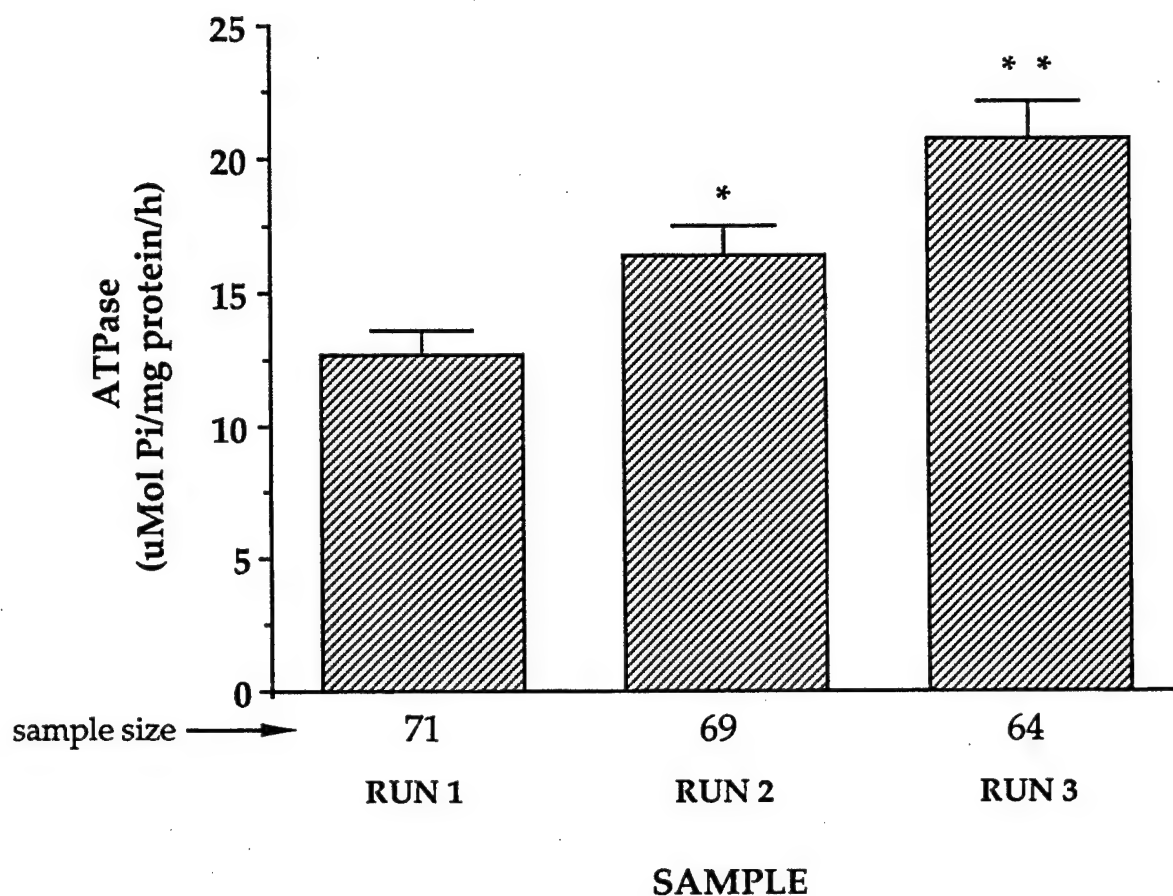
- Figure 17.** a) Scatterplot of level of bacterial kidney disease infection (BKD) on corresponding counts of plaque-forming cells (immune competence) from individual juvenile chinook salmon collected at Lower Granite dam and during barging. Values are included from all fish analyzed during the 1992 field season (N=164).
- b) The same data presented in part (a), except that BKD values greater than 100 have been eliminated (N=141, 23 values omitted). This allows the relationship of BKD to PFC's at low levels of BKD infection to be more clearly visualized.

a)

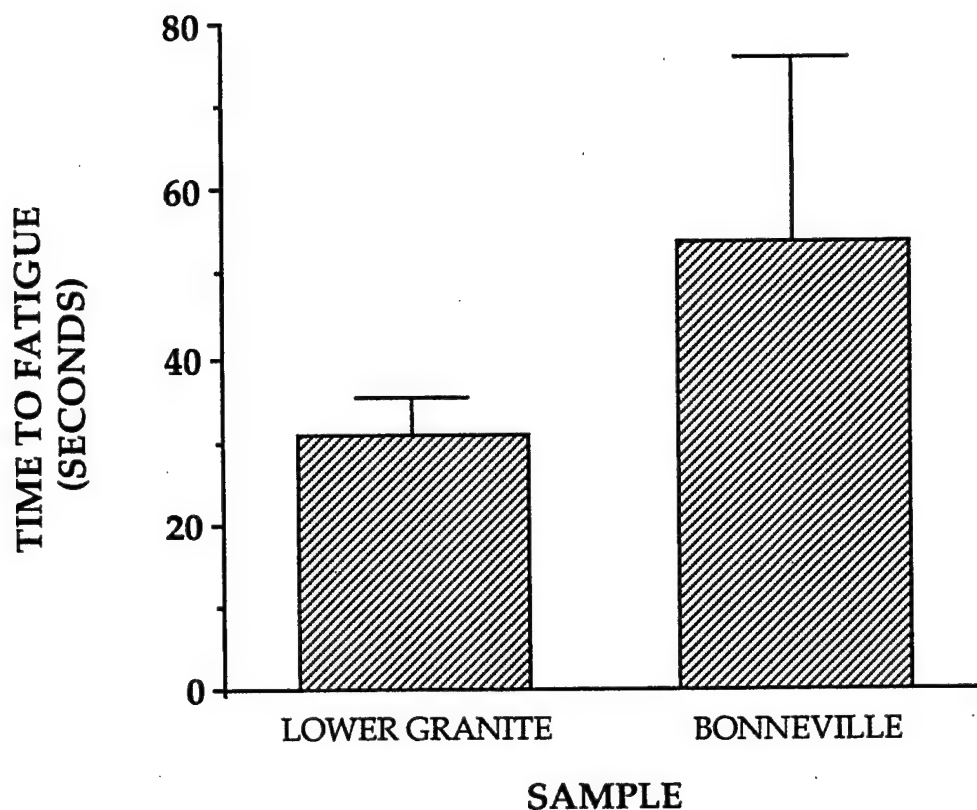


b)





**Figure 18.** Gill Na<sup>+</sup>/K<sup>+</sup> ATPase (mean + SE) of juvenile spring chinook salmon collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3). Each bar represents the pooled results of three samples collected from: (1) the Lower Granite gatewell, (2) the Lower Granite fish facility, and (3) from the barge "Chinook" shortly before arrival at Bonneville dam (1.5-2.5 h before release). An asterisk represents a significant increase in Na<sup>+</sup>/K<sup>+</sup> ATPase; Run 2 is significantly higher than Run 1, and Run 3 is significantly greater than Run 2 ( $p < 0.05$ , LSD test).



**Figure 19.** Swimming endurance of juvenile chinook salmon forced to swim at a velocity of approximately 60 cm/s. Fish were collected at the Lower Granite fish facility and from the barge "Chinook" as it was docked in the Bonneville Dam navigation lock (approximately 1.5 h before fish release) over the dates 16-18 May 1992. Both groups were from the same cohort of transported fish. Each bar represents the mean and SE for a sample of 4 fish. There is no statistical difference between the samples.

**Table 5.** Hatchery of origin for coded-wire tagged juvenile chinook collected at Lower Granite dam and during barge transportation. Samples were collected three times during the 1992 outmigration: 26-28 April (RUN 1), 4-6 May (RUN 2), and 16-18 May (RUN 3). Included are the total numbers of fish originating from each hatchery for all runs combined, as well as the total number of tagged fish (from any source) collected on each date. Finally, the percentage of fish that carried tags (Total Percent Tagged) out of all fish collected in each run is listed.

| HATCHERY | Dworshak | Little White Salmon |              |  |  | Lookingglass | McCall | Powell | Rapid River | Sawtooth | Total         |                |
|----------|----------|---------------------|--------------|--|--|--------------|--------|--------|-------------|----------|---------------|----------------|
|          |          | Kooskia             | White Salmon |  |  |              |        |        |             |          | Number Tagged | Percent Tagged |
| RUN 1    | 5        | 8                   | 0            |  |  | 9            | 9      | 0      | 4           | 6        | 42            | 21.9           |
| RUN 2    | 42       | 14                  | 1            |  |  | 4            | 11     | 0      | 1           | 0        | 81            | 42.9           |
| RUN 3    | 34       | 17                  | 1            |  |  | 3            | 2      | 2      | 0           | 3        | 74            | 40.4           |
| TOTAL    | 81       | 39                  | 2            |  |  | 16           | 22     | 2      | 5           | 9        | 197           | 34.9           |

accumulation of lactate, which could influence the post-release performance of these animals.

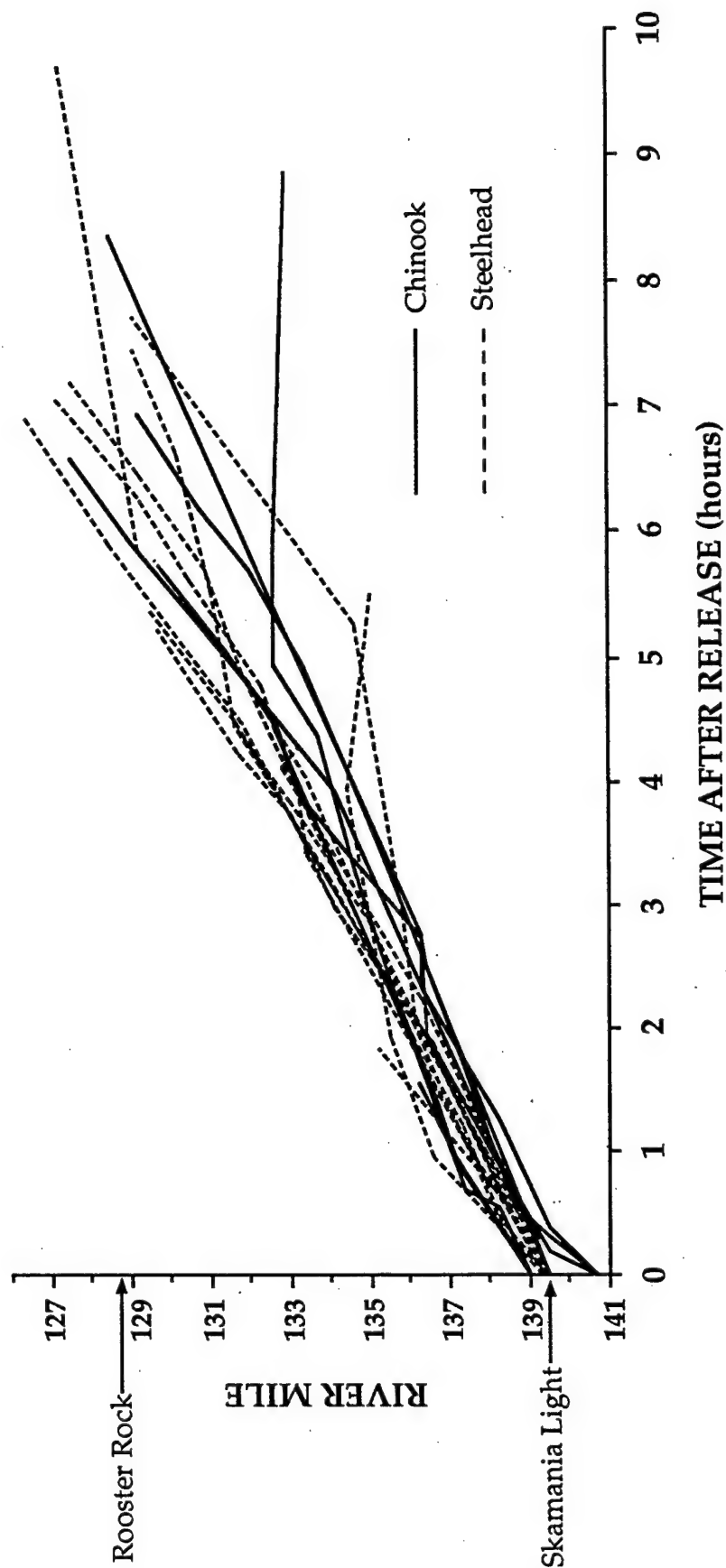
#### **Behavior of migrants post-release (objective 3B.2)**

Upon release, radiotagged fish rapidly left the release area, moving more than 0.5 mile within 15 minutes. The majority of smolts then traveled downstream at a rate of 1-2 miles/hour, although there was considerable variation between individuals (Figure 20). Individual fish may have sped up, slowed down, or stopped migrating (holding up) for various periods. There was no obvious difference in the speed of downstream travel between chinook salmon and steelhead trout, or in fish released on different release dates. Nearly all of the radiotagged fish we tracked to the exit of the study area (Rooster Rock) reached this point by mid-morning (0900 hrs). Most fish continued to migrate during the daylight hours.

The post-release movement patterns of radiotagged chinook and steelhead appear to be highly variable, but many individuals were observed in or near the shipping channel (Figures 21, 22, 23, 24, 25). Since the channel is the deepest part of the river and probably contains much of the flow, it seems reasonable that many of the released fish should be found here. Again, there were no obvious differences in behavior between chinook salmon and steelhead trout.

The migration patterns of many radiotagged individuals may have taken them through areas containing large concentrations of predatory squawfish. During predator indexing studies conducted in the month of May, the largest numbers of squawfish were collected along the shoreline in the vicinity of Multnomah Falls and Cape Horn (Figs. 21-25). In both of these areas the shipping channel hugs the shore, making a sweeping bend. The movements of the majority of radiotagged individuals took them through at least one of these areas, sometimes both, for each release studied.





**Figure 20.** Migration velocity of juvenile steelhead and chinook salmon released from transport barges near the Skamania light (downstream of Bonneville Dam at approximately Columbia River mile 139.5) and tracked to Rooster Rock (river mile 128.7). Data was obtained from fish released on five dates: 23 April, 6 May, 13 May, 19 May, and 25 May 1992. Each line represents an individual fish. Sample size is 21 (8 chinook and 13 steelhead).

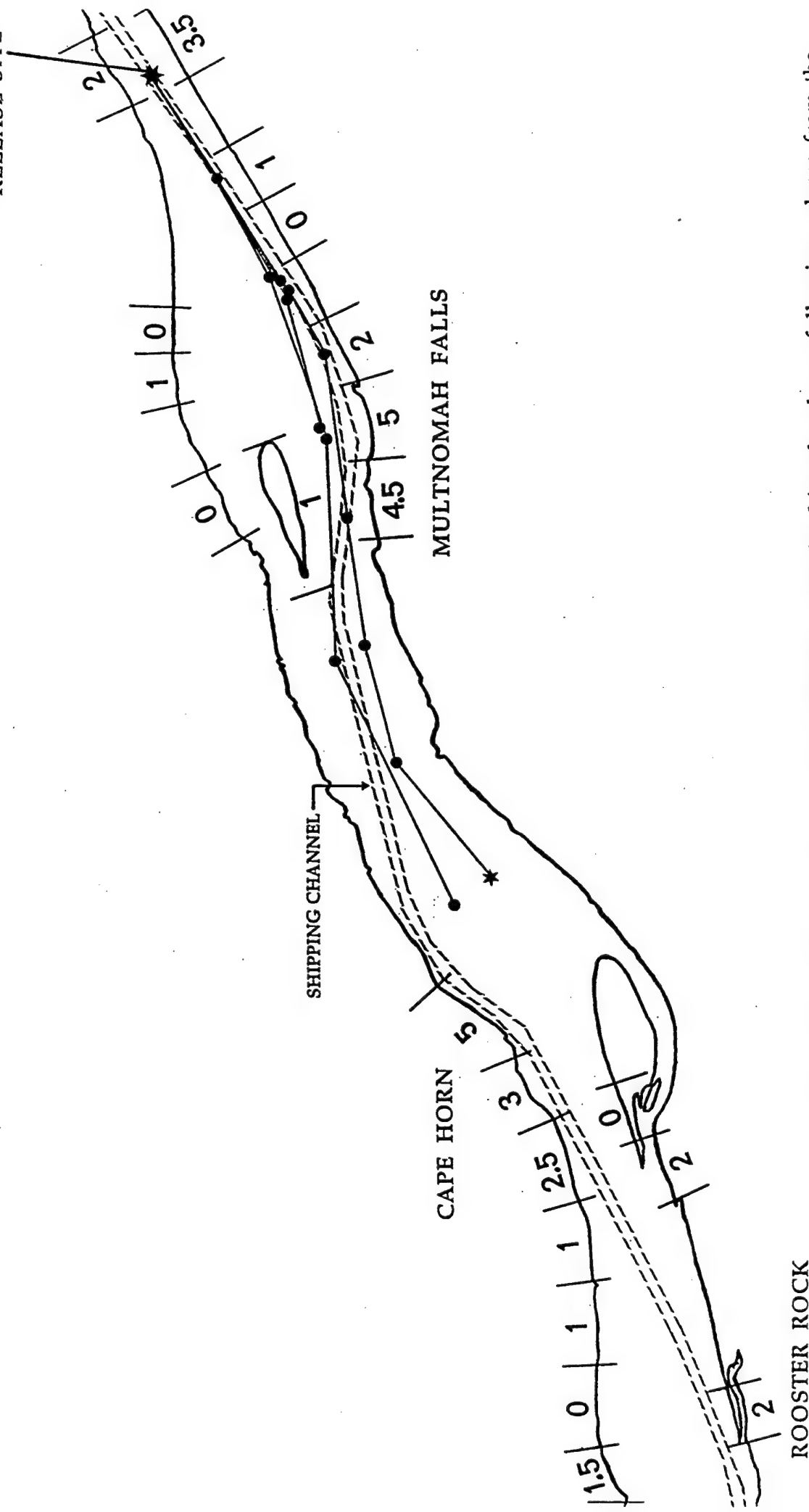


Figure 21.

Migration routes of individual juvenile chinook salmon following release from the barge "Chinook" on 23 April 1992. The location of each fish was determined using radiotelemetry; dots on the map represent points where a "fix" (location and time) was determined. A star indicates that the fish stopped moving and held at the marked location for at least 30 min.  $N=3$  (4 fish were released, but 1 fish was not located and was omitted from this figure). The bars and numbers shown along the river shoreline indicate electrofishing transects and the numbers of squawfish captured in each transect during 15 min of fishing. Electrofishing was conducted on 7-8 May (Multnomah reach) and 12-13 May (Rooster Rock reach).

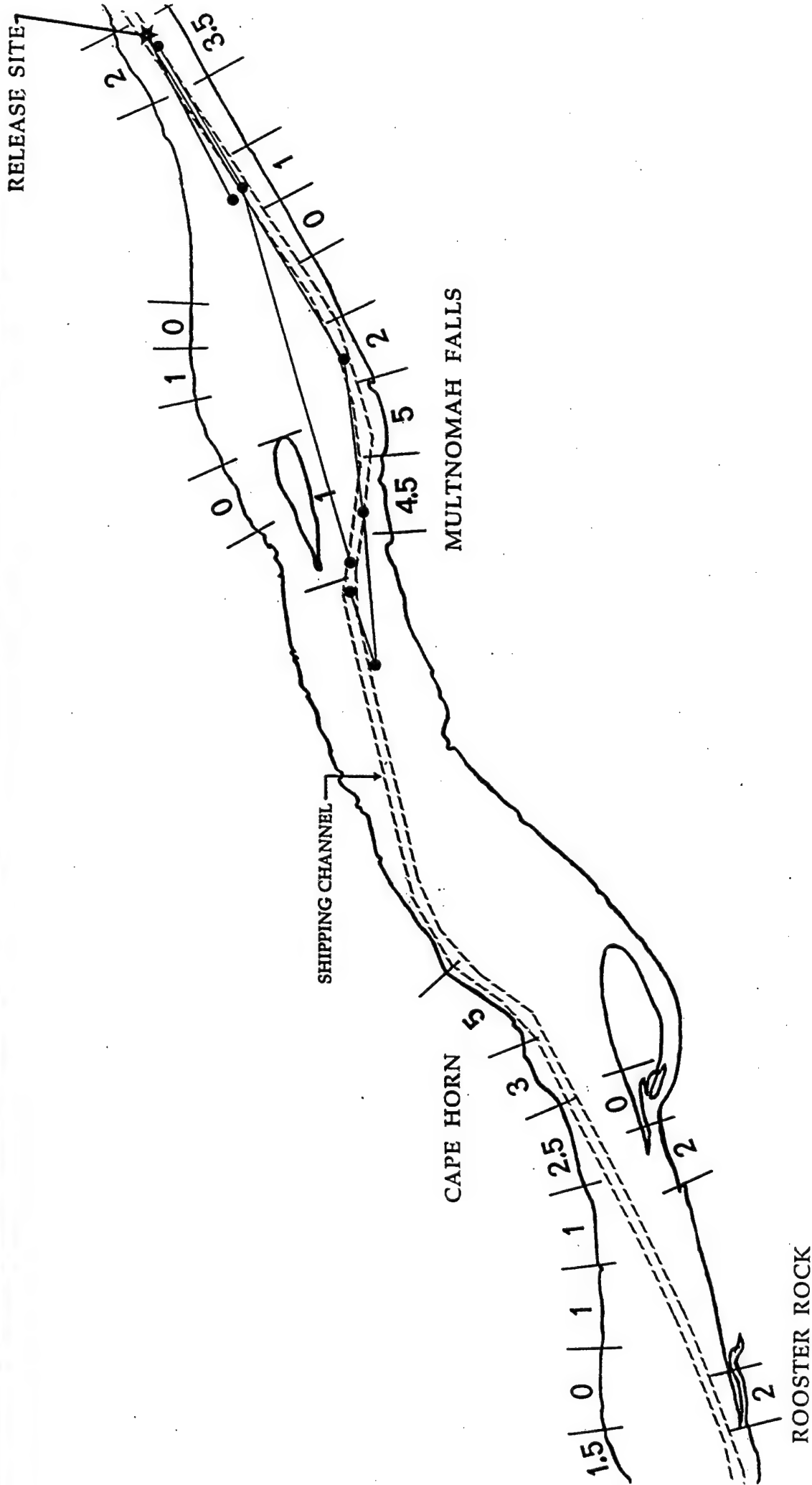


Figure 22. Migration routes of individual steelhead following release from the barge "Chinook" on 6 May 1992. The location of each fish was determined using radiotelemetry; dots on the map represent points where a "fix" (location and time) was determined. N=3 (6 fish were released, but 3 fish were not located and were omitted from this figure). The bars and numbers shown along the river shoreline indicate electrofishing transects and the numbers of squawfish captured in each transect during 15 min of fishing. Electrofishing was conducted on 7-8 May (Multnomah reach) and 12-13 May (Rooster Rock reach).

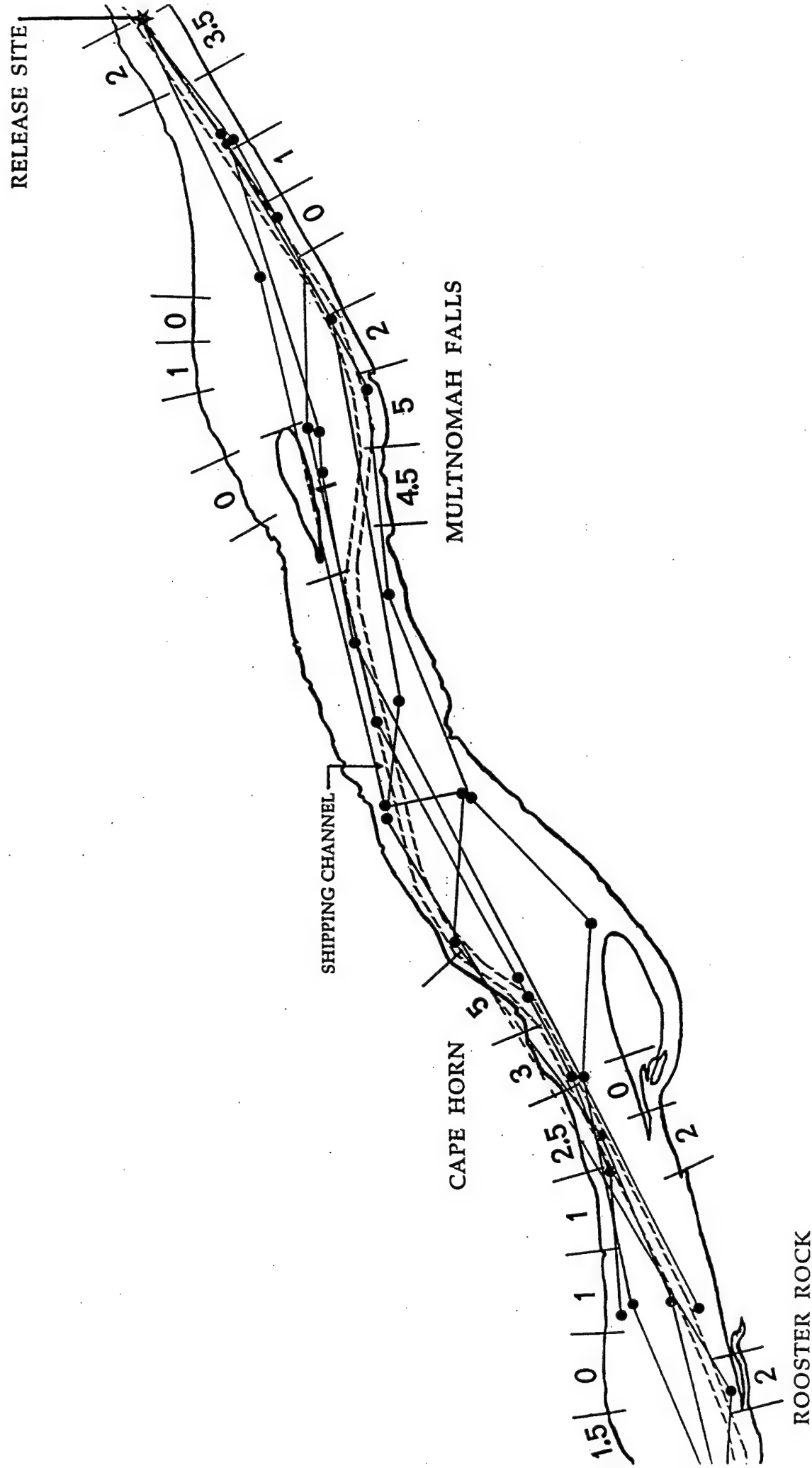
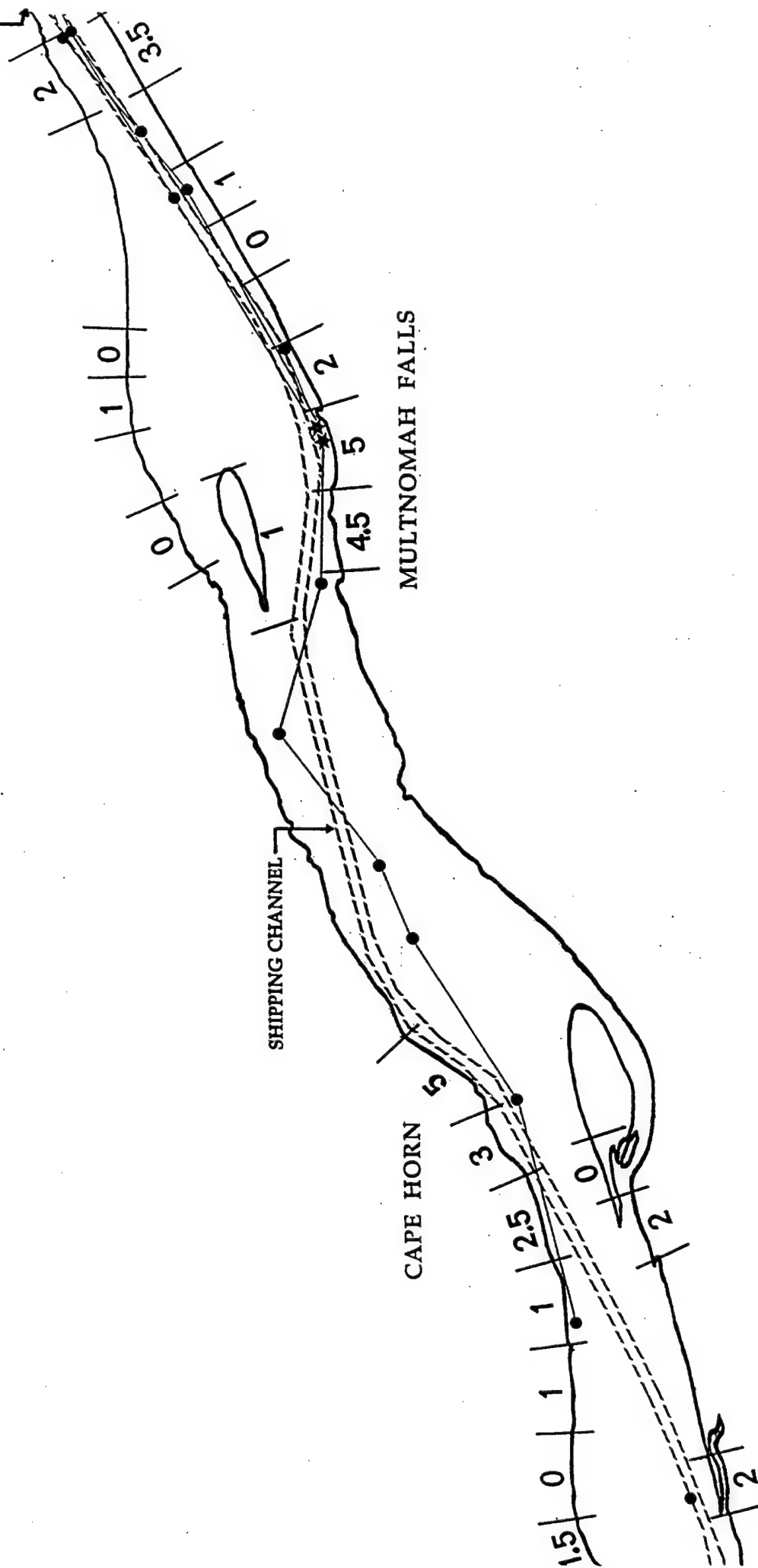


Figure 23. Migration routes of individual steelhead following release from the barge "Chinook" on 13 May 1992. The location of each fish was determined using radiotelemetry; dots on the map represent points where a "fix" (location and time) was determined.  $N=6$ . The bars and numbers shown along the river shoreline indicate electrofishing transects and the numbers of squawfish captured in each transect during 15 min of fishing. Electrofishing was conducted on 7-8 May (Multnomah reach) and 12-13 May (Rooster Rock reach).



ROOSTER ROCK

Figure 24.

Migration routes of individual juvenile chinook salmon following release from the barge "Chinook" on 19 May 1992. The location of each fish was determined using radiotelemetry; dots on the map represent points where a "fix" (location and time) was determined. A star indicates that the fish stopped moving and held at the marked location for at least 30 min.  $N=3$  (4 fish were released, but 1 fish was not located and was omitted from this figure). The bars and numbers shown along the river shoreline indicate electrofishing transects and the numbers of squawfish captured in each transect during 15 min of fishing. Electrofishing was conducted on 7-8 May (Multnomah reach) and 12-13 May (Rooster Rock reach).

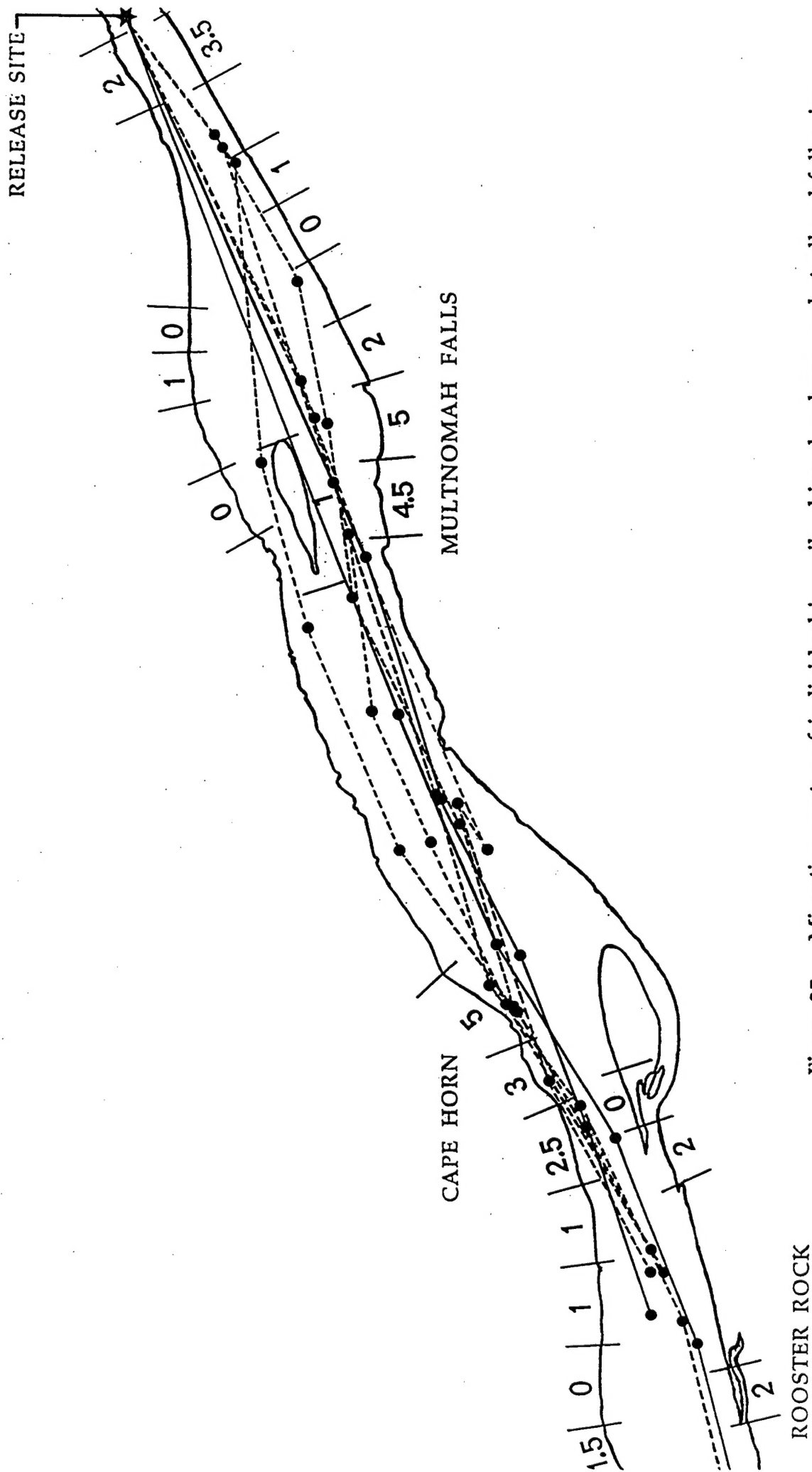


Figure 25.

Migration routes of individual juvenile chinook salmon and steelhead following release from the barge "Chinook" on 25 May 1992. The location of each fish was determined using radiotelemetry; dots on the map represent points where a "fix" (location and time) was determined. N=7 (8 fish were released, but 1 fish was not located and was omitted from this figure). The bars and numbers shown along the river shoreline indicate electrofishing transects and the numbers of squawfish captured in each transect during 15 min of fishing. Electrofishing was conducted on 7-8 May (Multnomah reach) and 12-13 May (Rooster Rock reach).

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